HYDROGEOLOGICAL STUDIES OF SPRINGS

IN AKAROA COUNTY,

BANKS PENINSULA

A thesis
submitted in partial fulfillment
of the requirements for the Degree
of
Master of Science in Engineering Geology
in the
University of Canterbury
by

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University of Canterbury
1986

With III Separate Maps in Back Pocket.

ABSTRACT

Akaroa County, which is situated on the eroded remnant of the basaltic Akaroa Volcano, is developing as a tourist and recreational area, with consequent increasing demands on water supplies. Improved utilisation of the springwater resource of the area is a possible solution to these demands and this thesis develops hydrogeological models for the springs to assist in their future management. Methods used in this study include detailed hydrogeological mapping of two specific areas, isotope and chemical analyses of springwater, and spring discharge monitoring over a one year period.

Groundwater discharge as springs and seeps is common in Akaroa County, with more than 200 springs mapped in the French Farm study area and 470 springs in Pigeon Bay Valley. Spring discharge may occur directly from defects in the basaltic lavas, but more commonly occurs through the surficial cover that mantles most of the area. Relatively impermeable beds (eg. tuff and unjointed lava) within the volcanic sequence are the dominant influence on spring distribution because of their perching effect. A "head"/storage groundwater model is proposed whereby water contained in heterogeneous lava "aquifers" is displaced to springs by infiltrating rainwater because of a pressure head applied to the irregularly shaped perched groundwater bodies.

Most springs flow at less than 2.5 litres per minute and discharges of greater than 15 litres per minute are uncommon. All monitored springs show high discharge variability (1780% for one measured spring), with peak discharge occurring in winter and the lowest flows in autumn. The "Abattoir Spring" in the summit region shows rapid (within 24 hours) response to storm events with subsequent peak flows occurring 2 to 6 days later. Groundwater recharge is the result of infiltration of local

precipitation, and the greatest potential for recharge occurs in the summit regions. Chemical quality of the springwaters is generally within the N.Z. Standards for Drinking Water, although nearly all samples show low pH values (pH = 6.0 to 7.3) and some show high iron and turbidity contents.

Proposed utilisation of springs for water supply will require preliminary discharge monitoring. If excavation of the spring is employed to increase yield then water budget analysis of the recharge area should be undertaken so that safe yields are not exceeded. Reticulation systems should incorporate treatment facilities to counteract low pH, turbidity, or high iron content where these exceed Standards limits. Future study should include detailed water budget work to determine the magnitude of the groundwater resource of Akaroa County.

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CHAPTER 4 : HYDROGEOLOGICAL STUDIES ON SPRINGS IN PIGEON BAY VALLEY

CHAPTER 5 : GROUNDWATER MODEL AND MANAGEMENT IMPLICATIONS

CHAPTER 1

INTRODUCTION

1.1 LOCATION

Akaroa County covers an area of 43,997 hectares and is situated on the eastern half of Banks Peninsula (Fig.1.1). Centred on Akaroa Harbour it extends eastwards from a line joining Big Bay in the north and Island Bay in the south and incorporates the eroded remnant of the extinct Akaroa Volcano, which reaches a maximum altitude of 841m at Saddle Hill.

Akaroa is the only urban centre, with smaller settlements distributed around the inside of Akaroa Harbour and the outer Peninsula rim.

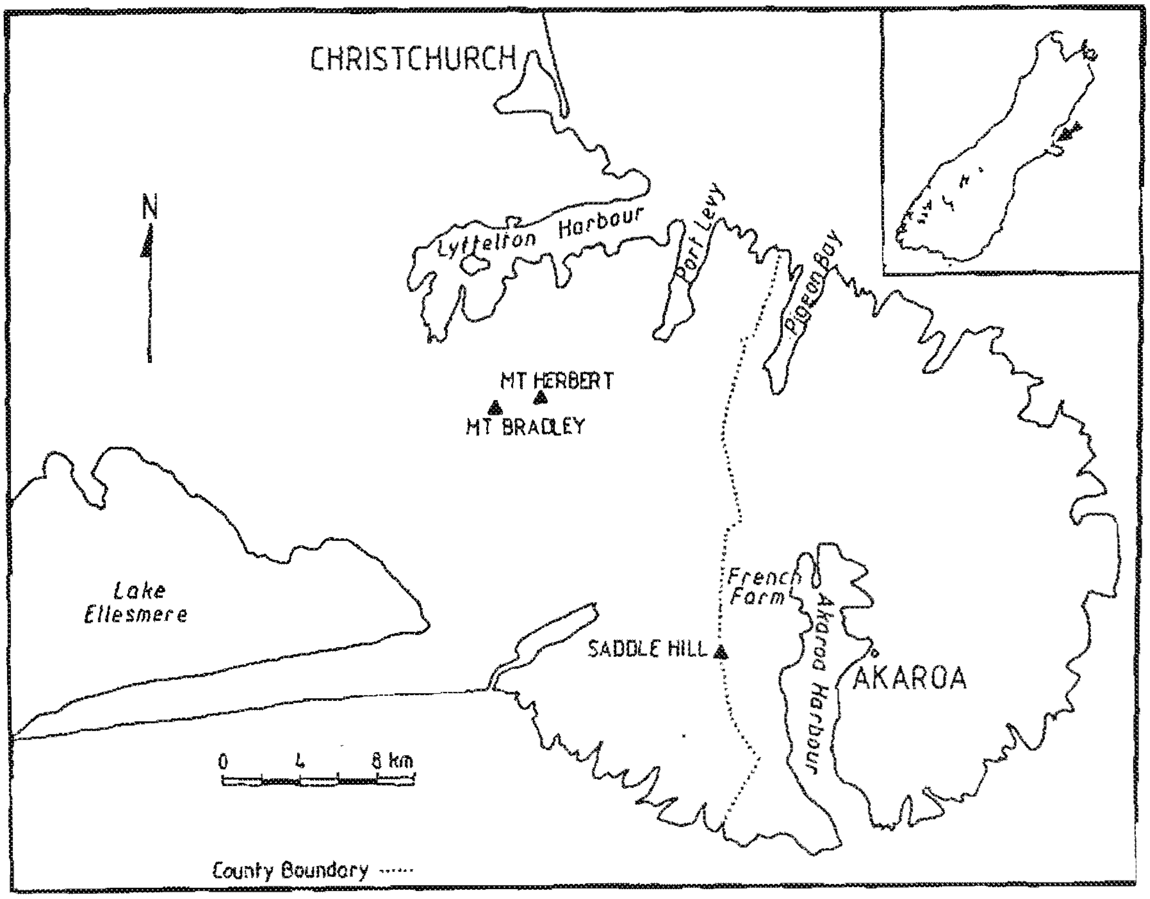


Fig. 1.1 Locality map showing Akaroa County and the studied areas (French Farm, Pigeon Bay, and Akaroa).

The permanent population of Akaroa County is 1910 (source: Akaroa County Council, 1984) with 1170 living in the rural area and 740 in the the township of Akaroa.

Future expansion of the township of Akaroa, and development of tourist and recreational services throughout the County, will put increasing demands on the present water supplies of the area. Better utilisation of the springwater resource of the County is a possible solution to these demands and this study has been instigated to gain an improved understanding of this resource.

1.2 GEOLOGY AND GEOMORPHOLOGY

1.2.1 Geological Evolution

The following outline of the geological setting of Akaroa County is based on Weaver et al (1985).

Banks Peninsula consists of two large eroded quaquaversally dipping basalt-trachyte volcanoes, Lyttelton and Akaroa (Fig. 1.2). They originally formed on the western end of the Chatham Rise (Liggett and Gregg, 1965). Folding or faulting due to the Kaikoura Orogeny are apparently absent.

The older Lyttelton Group lavas have yielded ages between 11 and 10 Ma. They consist of hawaiites and subordinate basalts, mugearites, and trachytes with intercalated pyroclastic units.

South easterly migration of volcanic activity occurred resulting in the Mt Herbert Volcanics between 9.7 and 8.0 Ma.

The Akaroa Volcano became active about 9.0 Ma at a centre near the present Onawe Peninsula building a 700m lava dome consisting of a succession of lavas ranging from basalt to trachyte with subordinate pyroclastics. Activity then waned and some basaltic magma crystallised in the volcano throat to give the gabbro of Onawe Peninsula. Intermittent activity continued and a second peak of activity occurred between 8.5 and 8.0 Ma. Large volumes of lava were erupted, building the cone to a height of approximately 1800m. This activity buried parts of the south eastern slopes of Lyttelton Volcano and interfingered with contemporaneous flows of Mt Herbert Volcanics. Towards the end of this activity a radial dyke swarm was formed within the Akaroa Volcano.

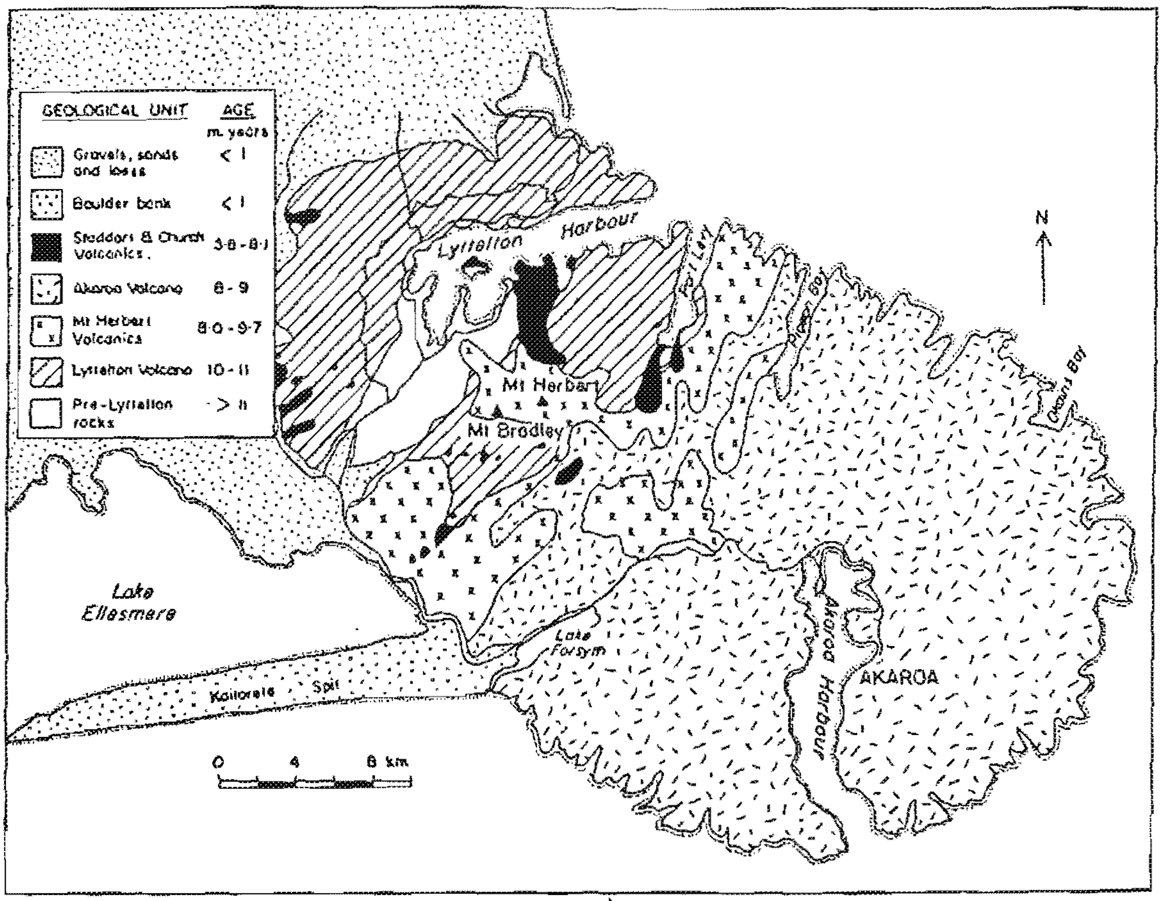


Fig. 1.2 Geological map of Banks Peninsula. (From Weaver et al, 1985).

The final phase of Banks Peninsula volcanism involved extrusion of a series of olivine-basalt lavas known as the Diamond Harbour Group from vents near Herbert Peak between 8.1 and 5.8 Ma. This lava flowed down the inner slopes of the established Lyttelton caldera and the eroded flanks of Lyttelton Volcano. Similar basalts were extruded from small vents at Halswell, Ahuriri, and Port Levy.

On cessation of volcanic activity a pattern of radial drainage channels became established on the Lyttelton and Akaroa cones. The main phase of cone dissection occurred over a period of 1.5 to 2 million years in the late Miocene or early Pliocene with subsequent erosion in response to low Pleistocene sea levels during glacial periods. Deep steep sided valleys formed along drainage lines with more resistant lavas forming the intervening ridges. One channel on the southern side of the Akaroa cone became dominant cutting back into the centre of the volcano. With the rise in sea level following the last glacial episode the crater was partly drowned and the modern Akaroa Harbour was formed. Lyttelton Harbour was formed in a similar fashion.

By the start of the Pleistocene (1.8 Ma) the two eroded volcanoes of Akaroa and Lyttelton formed an island 50 km from the mainland, but during the late Pleistocene glacial outwash gravels filled in the shallow seaway dividing the two.

During the Pleistocene widespread production of silt-sized material by glacial grinding and periglacial activity occurred. This fine grained material was transported by north west winds and deposited as an airfall blanket of loess on the eroded volcanic flanks, where it has become mixed to some extent with locally-derived volcanic material during slope movement processes to form colluvial deposits. Today loess cover is generally restricted to remnant patches at altitudes above 300 m, but redeposited volcanic bedrock- and loess-derived colluvial material can be up to 20m thick on the footslopes.

1.2.2 Geomorphological Setting

Akaroa Volcano in its present form consists of steep inner walls surrounding Akaroa Harbour, formed by truncation of outward dipping flows due to joint - controlled erosion, with more gently dip sloping outer walls. These slopes are dissected by deep steep sided valleys which have formed along drainage lines with more resistant lavas forming the intervening ridges.

Major valleys often exhibit flat alluvial floors grading into moderately angled lower slopes due to a loess apron. Moving upslope mixed colluvium (Section 2.5.2) becomes more prominent and bedrock outcrop increases, and steep resistant lava cliffs alternate with flat benches resulting from softer volcanic interbeds. These climb to the summit ridges which are generally rugged with much rock outcrop and form a rim to the Harbour area.

1.3 CLIMATE

The insular nature of Banks Peninsula and its upstanding relief give Akaroa County a climate distinguished from the adjacent Canterbury Plains by higher rainfall and fewer frosts (Table 1.1). Snow is common on the highest slopes during the winter months and often lies for several weeks on the tops, although its thickness is not great.

1.3.1 Rainfall

Rainfall distribution is summarised in Fig. 1.3 which shows a general trend of increasing rainfall with altitude. Precipitation commonly differs between valley mouth and valley head, the latter having a considerably damper climate. Generally a winter rainfall maximum and summer minimum is experienced, with 30% of the rainfall in the three winter months of June, July, and August when short but intense storms are experienced. Akaroa County has a humid climate with a mean annual rainfall of greater than 900 mm (Table 1.2 shows that considerable variation occurs within Akaroa County) while Christchurch is sub-humid lying between 600 and 800mm (Table 1.1). For the studied year the rainfall was about 33% below average (Table 1.2).

1.3.2 Winds

The three most prevalent winds, in decreasing order,

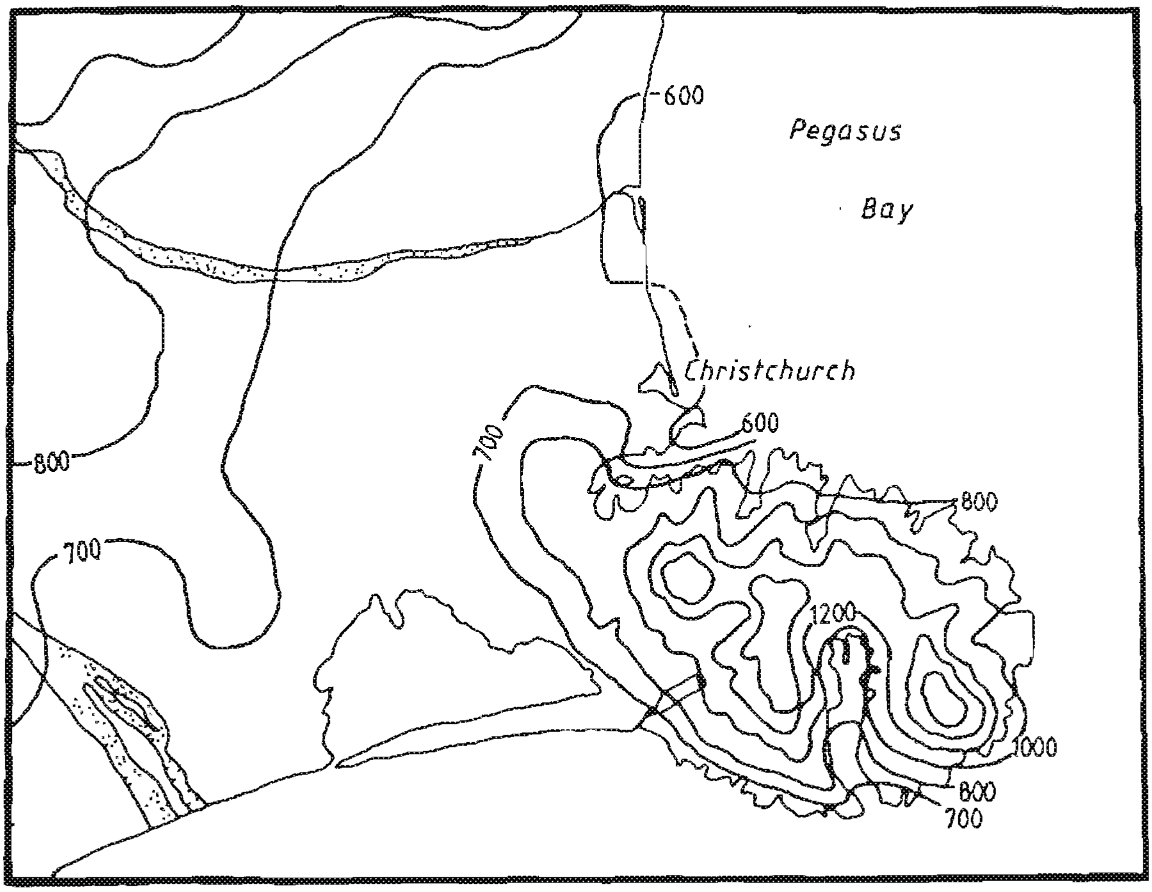


Fig. 1.3 Isohyets of mean annual rainfall (mm) for the years 1941 to 1970. NB. Isohyet separation is 100 mm for values less than 1000 mm, and 200 mm above this value. Source: N.Z. Meteorological Service.

are the northeasterly, southwesterly, and northeasterly (Washer, 1977). The southwesterly is the chief rain- and snow-bearing wind. Cold moisture-laden air, coming from the south west strikes the outer slopes of the Peninsula and experiences orographic lifting, with a resultant heavy precipitation on the upper slopes. Winds hitting the Akaroa Heads are deflected up the harbour onto the funnel-shaped walls at the heads of the various bays. On the higher levels at the head of the harbour the precipitation is augmented by fogs that spill over from the eastern slopes. The outer bays with a general easterly aspect receive a smaller southwesterly derived rainfall than the Harbour area because of a rain shadow effect.

The warm dry northwesterly wind is the second major influence on the Peninsula climate. It sweeps across the

H33181 ONAWE DUVAUCHELLE BAY — GRID REFS. NZMS 1, 1:63360 S094256278; NZMS 260, 1:50000 N36040163 — LAT. 43 46S LONG 172 56E HT. 46 M

	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL, MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1934-1980	185	248	268	431	328	233	415	310	278	141	160	277	1595
80 PERCENTILE VALUE	1934-1980	124	88	134	206	295	183	223	220	143	109	118	123	1305
MEAN	1934-1980	67	59	70	95	118	106	123	101	71	60	63	74	1007
10 PERCENTILE VALUE	1934-1980	24	16	20	27	38	28	55	37	23	21	22	14	775
LOWEST MONTHLY/ANNUAL TOTAL	1934-1980	15	11	1	10	12	7	15	26	6	13	10	1	643
AVERAGE RAIN DAYS, 1.0MM OR MORE	1934-1980	7	7	8	9	11	11	12	10	8	8	8	8	109
MAXIMUM 1-DAY RAINFALL	1934-1980	110	83	75	205	132	73	112	107	185	52	63	217	217
MAXIMUM 2-DAY RAINFALL	1934-1980	137	126	145	200	206	109	193	141	260	64	67	365	365
TEMPERATURE OF THE AIR, DEGREES CELSIUS														
HIGHEST RECORDED	1937-1972	35.0	35.6	32.0	31.1	26.2	22.3	19.6	21.0	24.3	29.1	30.0	32.2	35.6
AVERAGE MONTHLY/ANNUAL MAXIMUM	1937-1972	30.8	30.7	28.5	25.2	21.3	17.1	16.6	18.7	21.8	24.2	26.4	28.5	31.8
AVERAGE DAILY MAXIMUM	1937-1972	22.0	22.0	20.3	17.1	13.9	11.3	10.5	11.9	14.6	17.0	19.1	20.5	16.7
MEAN	1937-1972	17.1	17.1	15.6	13.0	10.3	7.8	7.1	8.1	10.3	12.3	14.2	15.7	12.4
AVERAGE DAILY RANGE	1937-1972	9.8	9.8	9.1	8.2	7.2	6.9	6.8	7.5	8.5	9.4	9.9	9.7	8.6
AVERAGE DAILY MINIMUM	1937-1972	12.1	12.2	11.1	8.9	6.7	4.4	3.7	4.4	6.1	7.6	9.3	10.8	8.1
AVERAGE MONTHLY/ANNUAL MINIMUM	1937-1972	7.0	6.9	5.9	3.8	2.0	0.1	-0.8	0.0	1.1	2.7	3.8	5.8	-0.9
LOWEST RECORDED	1937-1972	3.3	6.0	2.8	-0.6	-1.1	-2.6	-1.8	-2.1	-0.9	0.0	0.0	4.4	-2.6
TEMPERATURE OF THE GROUND, DEGREES CELSIUS														
LOWEST GRASS MINIMUM RECORDED	1937-1972	-2.3	-2.8	-4.0	-3.2	-8.6	-7.7	-7.9	-9.3	-9.3	-6.0	-4.8	-1.2	-9.3
AVERAGE GRASS MINIMUM	1937-1972	8.1	7.9	7.0	4.5	2.3	-0.2	-0.7	-0.1	1.5	3.8	5.7	7.5	4.0
FROST.														
AVERAGE DAYS OF GROUND FROST	1937-1972	0.2	0.4	0.3	1.6	6.4	14.0	16.9	14.5	3.6	2.5	0.6	.	63.3
AVERAGE DAYS OF AIR FROST	1937-1972	.	.	.	.	0.1	0.7	1.3	0.7	0.1	.	.	.	3.3
RELATIVE HUMIDITY, (%)														
AVERAGE AT 9 A.M.	1937-1970	67	68	73	75	78	79	81	78	70	67	67	68	73
SUNSHINE, TOTAL HOURS														
HIGHEST	1939-1972	288	232	252	213	139	145	142	170	232	258	262	278	2061
MEAN	1939-1972	216	185	171	134	89	83	96	129	164	193	205	205	1890
% OF POSSIBLE	1939-1972	48	49	46	43	35	37	35	42	49	49	48	44	45
LOWEST	1939-1972	139	137	102	66	65	58	56	64	108	118	140	137	1668
SPECIAL PHENOMENA, AVERAGE DAYS OF														
SNOW	1937-1972	.	.	.	.	0.1	0.5	1.0	0.2	0.1	0.1	.	.	2.0
HAIL	1937-1972	0.2	0.4	0.3	0.5	1.3	2.1	1.8	1.0	1.2	1.2	0.8	0.3	10.9
THUNDER	1955-1972	0.8	0.4	0.4	0.4	0.4	0.3	0.3	0.1	0.3	0.3	0.7	0.6	4.7
GALE	1937-1972	0.6	0.9	0.6	0.6	1.1	0.8	0.4	0.5	1.0	1.3	0.9	0.7	9.3
FOG	1937-1972	0.3	0.3	0.8	0.6	0.7	1.0	0.9	0.9	0.4	0.3	0.3	0.2	6.5

*H32581 CHRISTCHURCH — GRID REFS. NZMS 1, 1:63360 S084990563; NZMS 260, 1:50000 M35782419 — LAT. 43 32S LONG 172 37E HT. 7 M

	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL, MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1894-1980	139	176	187	226	233	191	221	197	156	160	137	201	1010
80 PERCENTILE VALUE	1894-1980	110	87	134	109	169	122	145	99	97	95	84	119	856
MEAN	1894-1980	55	43	54	56	75	63	71	53	47	47	48	58	666
10 PERCENTILE VALUE	1894-1980	19	11	12	17	19	21	23	20	10	10	14	13	479
LOWEST MONTHLY/ANNUAL TOTAL	1894-1980	6	1	3	6	12	4	6	2	4	1	3	1	379
AVERAGE RAIN DAYS, 1.0MM OR MORE	1902-1980	7	5	7	7	8	9	9	7	7	7	7	7	87
MAXIMUM 1-DAY RAINFALL	1873-1980	105	76	80	124	102	75	80	83	56	69	46	108	124
MAXIMUM 2-DAY RAINFALL	1873-1980	170	95	120	149	122	130	105	117	75	130	66	110	149
TEMPERATURE OF THE AIR, DEGREES CELSIUS														
HIGHEST RECORDED	1864-1980	36.2	41.6	33.4	30.1	27.0	22.5	27.8	23.2	27.3	31.4	32.2	35.0	41.6
AVERAGE MONTHLY/ANNUAL MAXIMUM	1864-1980	30.6	29.7	28.0	24.6	20.9	17.3	16.9	18.4	21.8	24.9	26.7	28.1	31.9
AVERAGE DAILY MAXIMUM	1864-1980	21.6	21.1	19.4	16.9	13.5	10.8	10.3	11.6	14.3	16.9	18.8	20.6	16.3
MEAN	1864-1980	16.4	16.3	14.8	12.1	8.9	6.3	5.9	7.0	9.5	11.9	13.7	15.6	11.6
AVERAGE DAILY RANGE	1864-1980	9.5	9.5	9.3	9.5	9.2	9.0	8.9	9.1	9.6	10.1	10.4	10.0	9.5
AVERAGE DAILY MINIMUM	1864-1980	11.6	11.5	10.1	7.4	4.3	1.8	1.4	2.5	4.7	6.8	9.5	10.6	6.8
AVERAGE MONTHLY/ANNUAL MINIMUM	1864-1980	5.6	5.7	3.3	0.7	-1.7	-3.3	-3.4	-2.8	-1.1	0.5	2.2	4.6	-4.0
LOWEST RECORDED	1864-1980	1.1	1.2	-0.8	-3.6	-5.9	-5.8	-7.1	-6.0	-4.8	-3.3	-1.5	0.8	-7.1
TEMPERATURE OF THE GROUND, DEGREES CELSIUS														
LOWEST GRASS MINIMUM RECORDED	1864-1980	-4.8	-7.0	-6.2	-11.3	-11.5	-14.9	-12.1	-12.9	-11.7	-9.0	-6.6	-8.3	-14.9
AVERAGE GRASS MINIMUM	1864-1980	9.0	8.7	7.2	4.1	1.1	-1.3	-1.6	-0.9	1.2	3.7	6.1	7.6	3.6
AVERAGE AT 30 CM DEPTH	1936-1980	20.3	19.5	17.0	13.7	9.7	6.3	5.3	6.7	9.6	12.9	16.4	18.7	13.0
AVERAGE AT 1 M. DEPTH	1936-1980	18.8	19.0	17.6	15.1	11.8	8.7	7.1	7.7	9.7	12.3	15.2	17.3	13.4
FROST.														
AVERAGE DAYS OF GROUND FROST	1864-1980	0.2	0.2	1.1	4.3	11.2	17.8	18.8	16.8	10.0	6.2	2.4	0.5	88.7
AVERAGE DAYS OF AIR FROST	1864-1980	.	.	..	0.6	3.4	10.0	11.3	7.8	2.2	0.4	0.1		35.7
RELATIVE HUMIDITY, (%)														
AVERAGE AT 9 A.M.	1928-1980	70	73	79	85	87	89	89	86	76	69	66	69	78
VAPOUR PRESSURE, MILLIBARS														
AVERAGE AT 9 A.M.	1941-1980	13.7	13.9	13.4	11.6	9.2	7.5	7.3	8.1	9.3	10.3	11.3	12.6	10.7
SUNSHINE, TOTAL HOURS														
HIGHEST	1935-1953	262	234	268	192	183	162	176	182	195	237	259	242	2200
MEAN	1935-1953	211	183	160	139	126	114	127	145	164	195	205	195	1974
% OF POSSIBLE	1935-1953	47	45	49	46	45	45	47	47	49	47	48	42	47
LOWEST	1935-1953	142	133	121	60	80	72	87	90	104	143	152	115	1873
SPECIAL PHENOMENA, AVERAGE DAYS OF														
SNOW	1867-1980	.	.	.	.	0.2	0.5	0.8	0.4	0.3	0.2			2.4
HAIL	1867-1980	0.3	0.1	0.2	0.4	0.4	0.5	0.5	0.4	0.6	0.4	0.4	0.3	4.5
THUNDER	1955-1980	0.4	0.1	0.2	.	0.1	0.1	0.1		0.1		0.2	0.2	1.5
GALE	1867-1980	0.9	0.8	0.6	0.6	0.7	0.5	0.3	0.6	0.9	1.0	1.1	1.0	8.9
FOG	1978-1980	0.2	0.5	1.2	1.8	3.2	3.8	3.3	2.4	0.9	0.3	0.3	0.3	18.1

*INCLUDES OBSERVATIONS FROM VARIOUS SITES IN CHRISTCHURCH FROM 1864-1905

Table 1.1 Comparison table of climatic factors as observed at Onawe Duvauchelle Bay (Akaroa County) and Christchurch. Source: N.Z. Meteorological Service Misc. Pub. 177.

Site	Altitude (m)	Observation Period	Mean Annual Rainfall (mm)	Rainfall High (mm)	Rainfall Low (mm)	Rainfall 1984-85 (Study Period)	1984-85 % below mean
Akaroa Township	3	1894-1982	1096	1749	444	790	28%
Akaroa Township	34	1978-82	1075	1146	811	703	35%
Onawe Duvauchelle Bay	46	1934-82	997	1593	546	633	37%
French Farm	205	1969-84	1413	2037	731	965	32%
Hilltop	440	-	-	-	-	1047	-

Table 1.2 Summary table of Akaroa County rainfall data including data from study period (September, 1984 to August, 1985).

Canterbury Plains and strikes the exposed faces of the Peninsula rapidly drying out the countryside and summit ridges.

The eastern bays receive most of their rain from the prevailing northeasterly wind. During the summer this is usually a sea breeze bringing little rain, but as part of a cyclonic system in the winter it brings continuous and often heavy rain. Again the rainfall increases further inland to a peak value at the summit region where it is supplemented by south west rain.

1.3.3 Frosts

The average annual number of frosts occurring in Onawe Duvauchelle Bay is 63.7, much fewer than the Christchurch average of 88.7 (Table 1.1). Frost frequency and severity generally increases with altitude (Washer, 1977). Higher regions experience more and heavier frosts than lower slopes and valley floors, especially where the latter are short and terminate at the sea.

1.4 VEGETATION AND LANDUSE

1.4.1 Vegetation

Podocarp forest covered most of Banks Peninsula until about 145 years ago (Ford, 1949). Dense forest was developed on sheltered slopes, especially at the head of Akaroa Harbour and in many of the outer bays, while on the more exposed upper slopes this diminished to sub-alpine scrub. On the bleak southerly outer slopes to the east and west of the Akaroa Heads tussock grassland provided the main cover.

Considerable modification of the vegetation due to sawmilling and burning has resulted in a new pattern with only isolated stands of bush, generally second growth, at the heads of valleys and on the steep less accessible slopes. Sub-alpine scrub is still found in many exposed rocky areas, but grasses now dominate the slopes with silver tussock and various introduced species prevailing (Hughes, 1970). Variation in pasture composition relates to slope aspect and degree of grazing and burning.

Vegetation modification by European man, accompanying the transition from sawmilling to an agricultural based economy, has lead to greater runoff and a greater development of the crack and fissure system in loess and loess colluvium (Hughes, 1970).

1.4.2 Landuse

Landuse in Akaroa County is reflected in its occupational structure (Table 1.3), with the population subdivided into those residing in Akaroa township, and those in the rural area. Since the 1960's Akaroa township has experienced a decline in its function as a service centre for the surrounding rural area (Washer, 1977). It has, however, experienced a rise in population and a new dependence on many forms of tourism (eg. motels, motor camps, holiday homes, and recreation for Canterbury residents) for part of its livelihood. The main areas of employment are in the commercial and professional groups reflecting the needs of the tourist industry.

OCCUPATION	AKAROA TOWNSHIP %	AKAROA COUNTY %
Primary industry		
- Farming	3	56
- Forestry and sawmilling	1	1
- Fishing	24	2
Manufacturing industry including dairy factories	-	3
Services (power, water, etc.)	4	4
Building and construction	6	4
Transport and communications	10	10
Commerce, professions, etc.	27	10
Others	5	5
Retired	20	5
	100%	100%

Table 1.3 Occupational structure in Akaroa (after Washer, 1977).

In the summer holiday period the population of Akaroa township is estimated to rise from 740 to 3160 residents (1984 estimate by Akaroa County Council). With this increasing trend towards the tourist industry greater demands are being placed on the local water supply with shortages of treated water occurring over recent summer periods.

In the rural setting farming still provides the main source of employment. Agricultural activities directed toward sheep and cattle fattening dominate within Akaroa County. Some dairying continues, though this has declined, with only one cheese factory, at Barry's Bay, remaining. Deer farming and very limited goat farming are recent introductions to the area.

The fertile valley soils of some of the gentler slopes have allowed some horticultural development (eg. the protea nursery of French Farm Valley) with consequent water supply needs.

1.5 WATER SUPPLY

The urban and rural populations of Akaroa County are generally dependent on groundwater for water supply. Present water supply schemes meeting the demands of the settlements of the area commonly derive their potable water from streams via filtration and/or chlorination systems. For example, Akaroa township is supplied by chlorinated water from two reservoirs that are fed by water piped from Aylmers, Balgueri, and Grehan streams. During dry periods the streams of Akaroa County appear to be dominantly spring-fed.

Many rural dwellings and farms derive their domestic and stock water supplies directly from spring sources.

Well drives within the County have been confined to alluvial material and have generally been unsuccessful.

Rainwater tanks are the presently-used alternative to groundwater supplies, though they tend to be mostly restricted to intermittently used holiday homes.

Because of increasing demands on present water supply schemes, especially at the settlement scale, it is appropriate that this study be undertaken to provide a greater understanding of the groundwater resource of Akaroa County with particular reference to the springs that are common within the area.

1.6 THESIS OBJECTIVES AND STUDY METHODS

1.6.1 Principal Objectives

The principal objectives of this thesis are as follows:

1) To investigate groundwater occurrence and flow yields at three selected areas within Akaroa County with a view to determining the hydrogeological models appropriate to the springs of the region.

2) To source the spring waters to determine whether or not a direct infiltration - recharge model is adequate to explain groundwater recharge within Akaroa County.

3) To determine water quality and the future potential of the springs as sources of potable water within Akaroa County leading to management recommendations.

1.6.2 Investigation Outline

To achieve the objectives outlined the following procedures have been undertaken:

a) Hydrogeological mapping of two locations, viz French Farm Valley (including French Hill), and Pigeon Bay Valley, at 1:10,000 scale (APPENDIX 3). The springs in the catchment of Akaroa township have also been mapped at a scale of 1:10,000 for management purposes.

b) Monthly discharge monitoring of selected springs for a one year period, to delineate any seasonal variation (APPENDIX 9).

c) Daily flow monitoring of one spring and the adjacent rainfall for a six week period to detect fluctuations relating to local storm events (APPENDIX 9).

d) In situ permeability testing (APPENDIX 8) of regolith materials, and laboratory porosity testing (APPENDIX 7) of bedrock samples, as indicators of water bearing properties of the geological materials of the area.

e) Isotopic (deuterium and oxygen-18) testing (APPENDIX 4) of water samples from twelve selected springs of varying altitude or geological source to test a direct infiltration recharge model.

f) Sourcing of several springs on French Hill using Rhodamine Wt dye (APPENDIX 6).

g) Chemical testing (APPENDIX 5) of eleven springs to determine water quality and to assist in sourcing waters.

CHAPTER 2

GEOLOGICAL OCCURRENCE OF SPRINGS IN AKAROA COUNTY

2.1 INTRODUCTION

The spring waters of Akaroa County are intimately related to the volcanic rocks - basic lava flows, intrusive rocks, and pyroclastic beds - and surficial deposits that compose the present - day remnant of Akaroa Volcano. The quaquaversally dipping lava flows and intercalated subordinate pyroclastic beds lie on a partially exposed basement of trachytic flows, tuffs, and breccias intruded by the gabbro and syenite of Onawe Peninsula (Falloon, 1982). The sequence emplaced above this basement resulted from extrusion of basic lavas in the aa condition from a centre near Onawe Peninsula. Occasional explosive eruptions gave rise to pyroclastic material while the intrusive rocks of the Akaroa dyke swarm were probably emplaced at different times throughout the volcanic history (Falloon, 1982). More recent surficial deposits of aeolian and weathering origin restrict volcanic exposure and often confine groundwater.

The nature and water - bearing properties of the volcanic rocks and surficial materials as they relate to the occurrence of springs in Akaroa County are described in this chapter.

2.2 AKAROA GROUP LAVAS

The lavas of Akaroa County form heterogeneous aquifer systems with groundwater often contained in, or transmitted through, permeable (hydraulic conductivities between 10^{-2} to 10^{-7} m/s are expected (Freeze and Cherry, 1979)) basalt flows.

2.2.1 Composition

Falloon (1982), in petrographic and geochemical studies of the lavas of Wainui and French Farm, distinguished basalts and hawaiites with minor mugearites and benmoreites. Subordinate trachyte lava flows have also been identified. For the purposes of this study, however, lava compositions have not been distinguished in this detail. Fresh to slightly weathered phyric and aphyric basalts predominate, the phyric containing phenocrysts of all or some of the minerals olivine, augite, and plagioclase, while the aphyric often exhibit well developed flow - banding.

2.2.2 Flow Orientation and Thickness

The quaquaversally dipping lavas, when extrapolated, appear to radiate from near Onawe Peninsula. Dip values near the present summit vary between 3 and 15 degrees. The higher values are rare however and beds are frequently almost horizontal (Speight, 1944).

Flow thickness is very irregular, being determined not only by distance from the centre of extrusion (generally thinning away from this centre), but also the pre - existing topography on the volcano's flanks. Thicknesses of greater than 20 m have been observed for individual flows but these may thin or pinch out completely over topographic highs.

2.2.3 Flow Morphology

Aa flows exhibiting rubbly tops and basal breccias surrounding unbrecciated central lava are the typical flow form (Figs. 2.1, 2.2). However some flows do not exhibit these breccia types due to viscosity variations.

Brecciated tops form when a crust on the cooling lava flow breaks into discrete blocks as the less viscous flow centre continues to move. Fragments composing rubbly tops

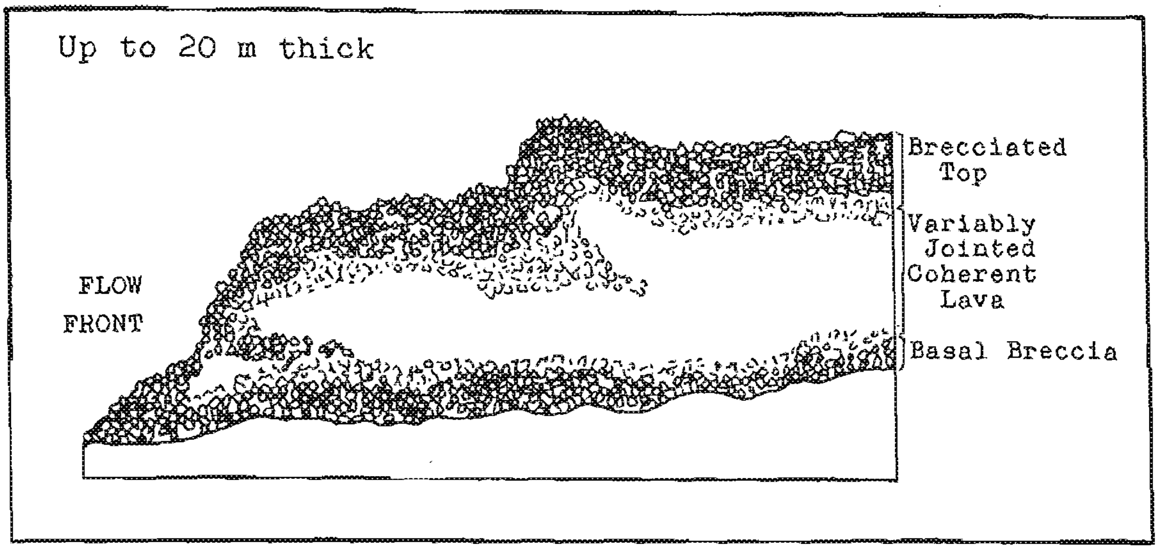


Fig. 2.1 Cross section through typical aa basalt lava flow as preserved in Akaroa County (after Weaver et al, 1985).

are generally less than 15 cm across but range between 1 mm and 1 m. Thicknesses of up to 5 m are observed.

Basal breccias are commonly thinner and less continuous than brecciated tops and consist of chilled blocks from the flow base or that fall from the flow front and are subsequently overrun by the less viscous central lava.

The fragmented breccias grade into the more coherent lava centre (Fig. 2.3) which typically shows some form of jointing and occasionally some vesicularity.

2.2.4 Jointing

Extremely variable jointing (Figs. 2.4, 2.5, 2.6) is characteristic of the Akaroa Group lavas with spacing, persistence, and aperture changing rapidly within the same flow, and determining whether it will readily transmit and store water or act as a perching layer. Joint character relates in part to flow thickness and also to distance from chilled flow margins; a general increase in joint spacing occurs with distance from these margins. Weathering may

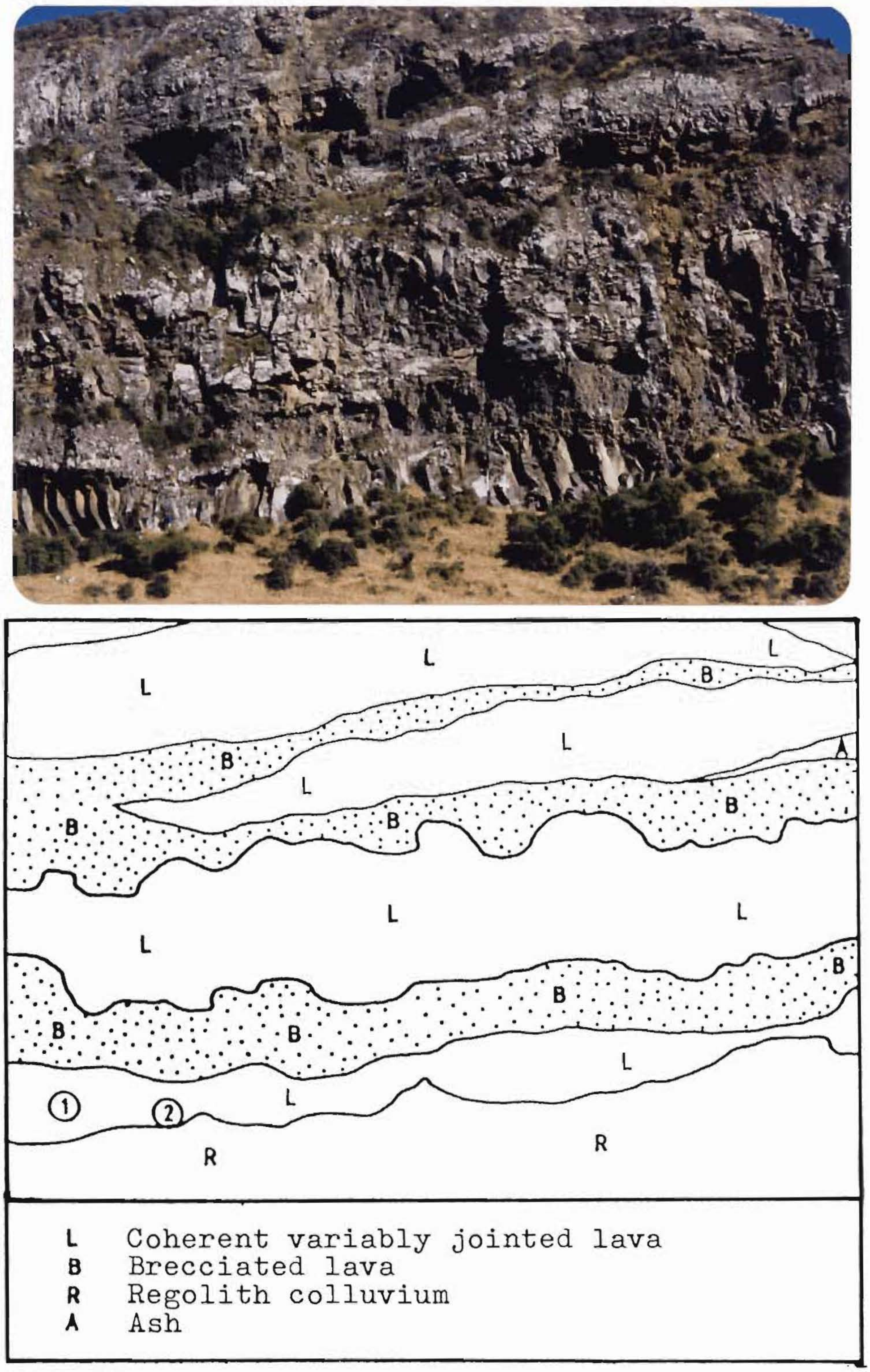


Fig. 2.2 Sequence of aa lava flows (and intercalated ash) as observed in Akaroa Volcanics in the Wairewa County gravel pits (Grid ref. M36 858 104).

1 columnar jointed basalt

2 person for scale

Fig. 2.3 Outcrop showing weathered basal breccia (on which hammer is placed) grading up into more coherent jointed lava. An ash layer separates the basal breccia from an underlying weathered brecciated top (Grid ref. N36 073 214).

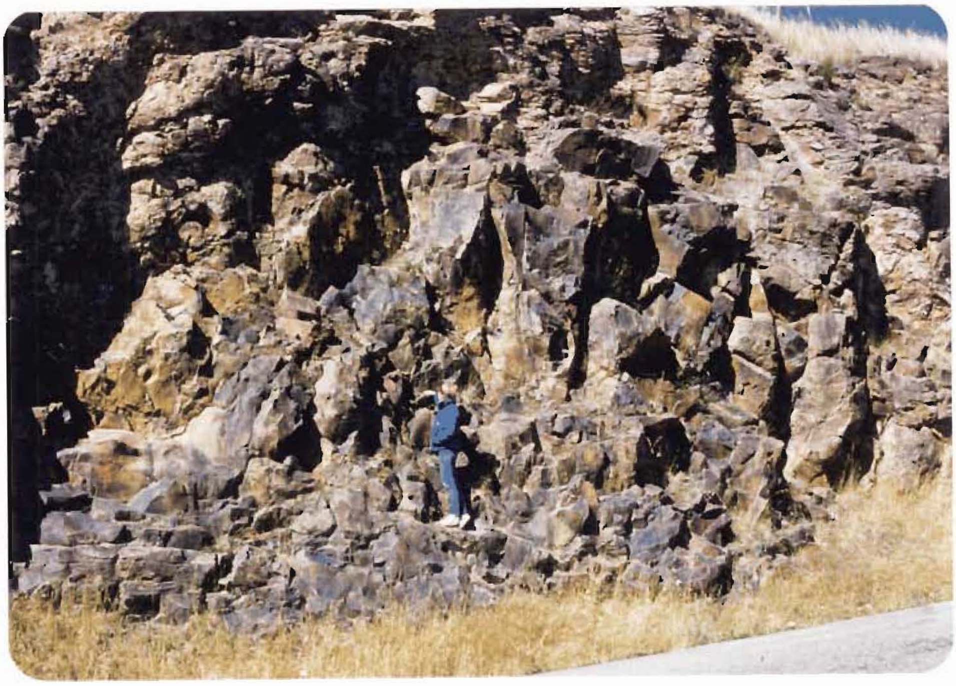


Fig. 2.4 Photo showing variability of jointing within a single lava flow. Joints within this outcrop are generally tight and would allow slow (about 10^{-7} to 10^{-9} m/s) infiltration (Grid ref. N36 998 172).

Fig. 2.5 Massive poorly jointed lava. Exposure is about 6 metres high (N36 000 196).

Fig. 2.6 Open jointed lava (aperture up to 3 cm) in summit region (N36 000 187).

result in expansion of the mineral constituents of the rock with subsequent reduction of joint aperture.

Generally one group of joint sets approximately normal to the flow surface and another sub - parallel to it divide the lava into irregular blocks (though these are often more or less cubic in shape with an average block size of between 100 and 450 mm, but ranging up to greater than 2 m). It is assumed that shrinkage due to cooling has produced most of the vertical joints and Yetton (1983) has suggested that the sub - horizontal joint sets, often parallel to flow banding, may be an exfoliation feature. Joint spacing varies from less than 1 cm to greater than 2 m with the horizontal joint set generally the more closely spaced. The average joint spacing for vertical sets is about 30 cm with apertures up to 3cm.

Well developed, though irregular, columnar jointing (Fig. 2.2) is observed occasionally and is most common in phyric basalts.

Joint infillings are usually only visible near to exposed weathering surfaces or surficial deposits and consist of weathering products or colluvium material. Calcite, probably a precipitate from circulating magmatic or post - volcanic waters, occurs rarely in some joints.

2.2.5 Vesicularity

Massive lavas infrequently show vesicularity (Fig. 2.7), most vesicles being less than 1 cm (average 4 mm) in diameter, and where present is generally less than 30% (up to approximately 50%) of the rock material volume. A general lack of jointing is observed with most vesicular lava tops.

2.2.6 Water - Bearing Properties of Lava Materials

Discontinuities within the Akaroa Group lavas make

HYDROGEOLOGICAL MAPPING UNIT	MODE OF OCCURRENCE	GENERAL ENGINEERING GEOLOGICAL DESCRIPTION (APPENDIX 1)	MATERIAL POROSITY	WATER-BEARING PROPERTIES
BASALTIC LAVAS (AKAROA GROUP)				
1) Coherent lava centre	Coherent lava may constitute all or a section (typically the middle of a single lava flow). Where brecciated layers are present get gradational contacts with coherent lava centre. Up to 20 m thick.	<u>Unweathered</u> Fresh to slightly weathered, very strong, grey to black, phyric to aphyric, medium to finely crystalline BASALTIC rock. Infrequently shows vesicularity. Contains at least 3 joint sets with highly variable nature. Aperture: tight to 3 cm. Spacing: <1 cm to > 2 m. Average block size is 100 to 450 mm. <u>Weathered</u> Moderately to highly weathered, moderately strong to very weak, dark to light grey or purplish grey, phyric to aphyric, BASALTIC rock. Jointing as above, but aperture may decrease where highly weathered.	Unweathered basalt = 1.5% Unweathered vesicular = 35% Weathered basalt = 57%	Open jointed lavas provide the main vertical flow path for infiltrating water. Thick bedded lavas showing tight or widely spaced jointing show relatively low water-bearing capacity and often act as barriers to vertical groundwater movement. Highly weathered lavas undergo considerable reduction in permeability from unweathered state. Commonly occur as perching layers.
2) Brecciated lava	May constitute all or sections (typically top or bottom) of a single lava flow. Gradational contact with coherent lava.	<u>Unweathered</u> Consists of clasts (up to boulder size) of the above unweathered basalt (usual basal breccias). <u>Rubbly Lava</u> Slightly to highly weathered clasts (up to boulder size) of massive BASALTIC lava in matrix of; slightly to highly weathered, soft to hard, dark to light grey, mixture of silt, sand and gravel sized fragments of basaltic lava. Predominantly unjointed.	as above (unweathered) basalt) Rubbly lava = 54%	Common medium for lateral groundwater flow in Akaroa County. Common perching layer due to lack of jointing.
PYROCLASTIC MATERIALS				
1) Ash and Tuff	Intercalated with Akaroa Group Lavas. Smooths out pre-existing topography and may fill cavities in underlying breccias. May be baked by overriding lavas.	Slightly to moderately weathered, moderately strong to very weak, red, massive or finely layered, BASALTIC tuff or ash. Predominantly unjointed.	Baked tuff = 39% Crystal tuff = 26%	Effectively impermeable. Most important barrier to vertical groundwater flow in Akaroa County.
2) Bedded Scoria	As for ash and tuff.	Slightly to highly weathered clasts (up to boulder size) of massive or frothy BASALTIC lava - in a matrix of slightly to highly weathered, moderately weak to strong, grey to purplish grey (or red) BASALTIC ash. Predominantly unjointed.	Unweathered scoria = 21% Weathered scoria = 74%	Effective perching layer because of unjointed nature.
INTRUSIVES				
1) Trachyte dykes	Vertical or sub-vertical trachytic sheets cutting lava flows and pyroclastic country rock.	Slightly to moderately weathered, very strong to moderately strong, greyish or greenish white, coarsely layered or massive TRACHYTE.	Moderately weathered trachyte = 19% (See Appendix 7)	Effective barrier to lateral groundwater flow.

<u>Table</u> <u>2.1</u> Engineering geological descriptions and water - bearing characteristics of the Akaroa Group Volcanics.

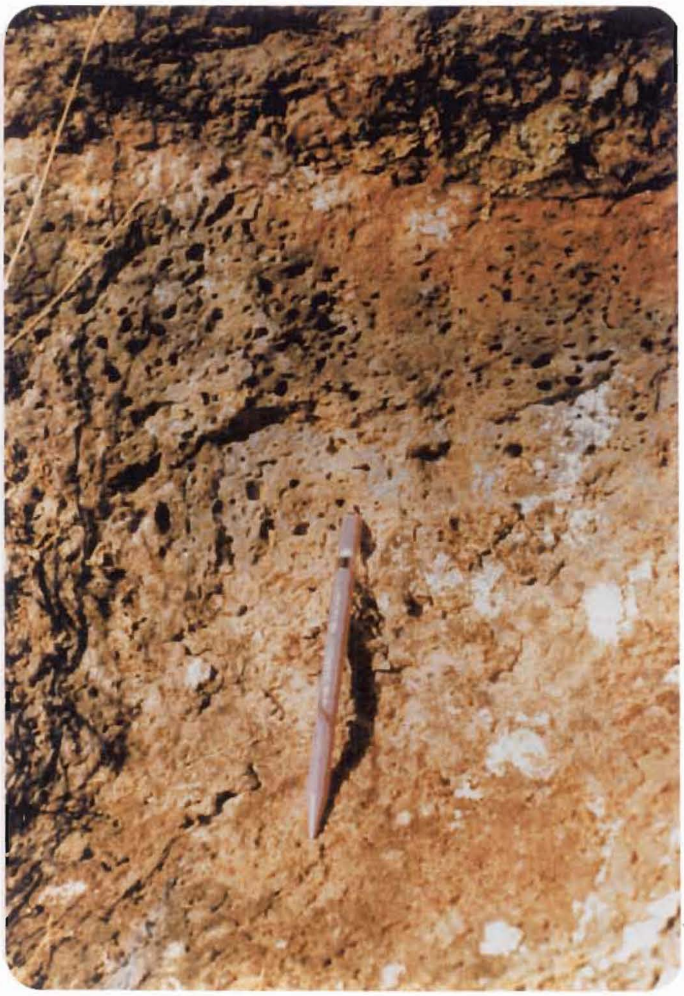


Fig. 2.7 Vesicular basalt lava top with thin (1 to 4 cm) ash layer above (shows as deep red band). Vesicles are 2 mm to 1 cm across. Outcrop occurs in Pigeon Bay. (Grid Ref. N36 038 219)

Fig. 2.8 Downward movement of water through shrinkage cracks in basalt lava shown by leakage from these cracks (seen as dark patches). (N36 034 244)

them the main perched aquifers in Akaroa County. Table 2.1 summarises the engineering geological and consequent aquifer characteristics of the lava materials.

Secondary permeability of lavas due mainly to cooling joints provides the main vertical flow path for percolating water (Fig. 2.8). Thin bedded lava flows showing well developed jointing (especially columnar jointing) can be excellent aquifers and allow rapid infiltration (up to 10^{-2} m/s) where they are exposed. In thick bedded flows the relative amounts of breccia and the size and frequency of the cracks that transmit water freely are less than in thin flows, and the water - bearing capacity of thick bedded sections of lava is relatively low. These lavas serve as perching layers where the overlying strata is more permeable.

In the process of weathering the mineral constituents of the lavas expand during chemical decomposition. This expansion reduces the size of the openings in the rock, and weathering is usually accompanied by a considerable reduction in permeability and a decrease in water - bearing capacity of the rock mass. As a result deeply weathered unbrecciated lava may lose its jointing and commonly forms a perching layer.

Weathering, resulting in the formation of clay minerals, and burial by subsequent flows and pyroclastic deposits, may compact brecciated tops, while deposition of secondary minerals (eg. calcite) by circulating water tends to reduce the pore space. Relatively impermeable rubbly lava beds (Fig. 2.3) may form as a result of these processes and are common perching layers. In spite of this some rubbly tops remain highly permeable and can be among the best aquifers.

Basal breccias, where less exposed to weathering, consist of coarse clastic material with insignificant matrix and form a common medium for horizontal groundwater flow in Akaroa County. When alteration occurs basal breccias form the same relatively impermeable rubbly lava beds as brecciated tops.

2.2.7 Aquifer Characteristics

Table 2.1 summarises the porosity/density properties of various lava flow materials as determined in a laboratory testing programme (Appendix 7). The highest porosity values (between 54% and 74%) belong to highly weathered lavas and brecciated layers. These materials are commonly seen as perching lithologies. Weathered vesicular basalts are also in this category. Those materials with the lowest porosities, ie. the unweathered basalts (1.5%), are found to be the best aquifers when breccias or closely spaced and open jointing are present indicating that rock mass permeabilities are more influential in water transmissivity than material porosity.

2.3 PYROCLASTIC MATERIALS

2.3.1 Ash and Tuff

Basalt - derived ash and tuff is commonly exposed as deep red beds of irregular thickness (Fig. 2.9). Some ash beds are very extensive being continuous for several kilometres, while others thin and pinch out locally. Generally ash beds are thicker in the vicinity of the vent but will smooth out irregularities of the pre - existing ground surface, resulting in deeper deposits where gullies have been infilled and shallower over topographic highs. Thicknesses up to about 4 metres have been observed. Usually ash or tuff is uniformly composed of silt - sized particles, but some graded bedding is observed with crystal tuffs (composed of olivine, augite, and plagioclase crystals) (Fig. 2.10) or occasional lapilli or bomb - rich layers grading up into homogenous ash.

Tuff beds are effectively massive with microjointing occurring mostly in weathered exposures. Baking of many

Fig. 2.9 Deep red ash / tuff layer exposed in road cut beside the Summit Road (N36 098 180). Note lack of jointing.

Fig. 2.10 Hand specimen samples of basaltic tuff: tuffaceous ash on left of pencil; crystal tuff (containing crystals of olivine, augite, and plagioclase in silt - sized ash matrix) on right.

tuff beds has added to their impermeability, and although porosity figures of around 38% for baked ash and 26% for crystal tuff have been derived (Table 2.1) they are probably the most important perching layer within the Akaroa sequence. Leakage may occur where these are discontinuous however.

2.3.2 Scoria

Parasitic cones of ash, scoria, and agglomerate occur in the Akaroa sequence, but of more importance from a hydrological point of view, are extensive and often thick (20 m+ exposed) bedded scorias (Fig. 2.11). Following the dip of the existing lava flows these beds are normally purplish grey in colour but may be stained red due to hot steam blasting through and oxidizing iron in the rock. Many scoria beds are now indurated, but initially consisted of loose frothy basalt-derived material (with a wide size range of constituent fragments but only a small proportion less than 1 mm) (Fig. 2.12). Unweathered and weathered indurated scorias give porosities of 21% and 74% respectively, the former due mainly to the frothy nature of basaltic clasts within the scoria. The higher porosity of weathered scoria is due to expansion of mineral constituents during chemical decomposition which leads to a more open structure within the material. However, despite these high porosity values the generally unjointed nature of scoria beds means they act as effective perching layers (Table 2.1).

2.4 INTRUSIVE ROCKS

The Akaroa Group includes a radial dyke swarm consisting mainly of trachyte with subordinate basalt and dolerite. The radial dyke pattern is well developed in its outer parts but becomes more criss - crossed near the point where the outlying dykes converge, ie. Onawe Peninsula.

Porosity testing of moderately weathered Pulpit Rock trachyte gives a value of 19%, but the tight nature of observed joints means that Akaroa intrusives present an

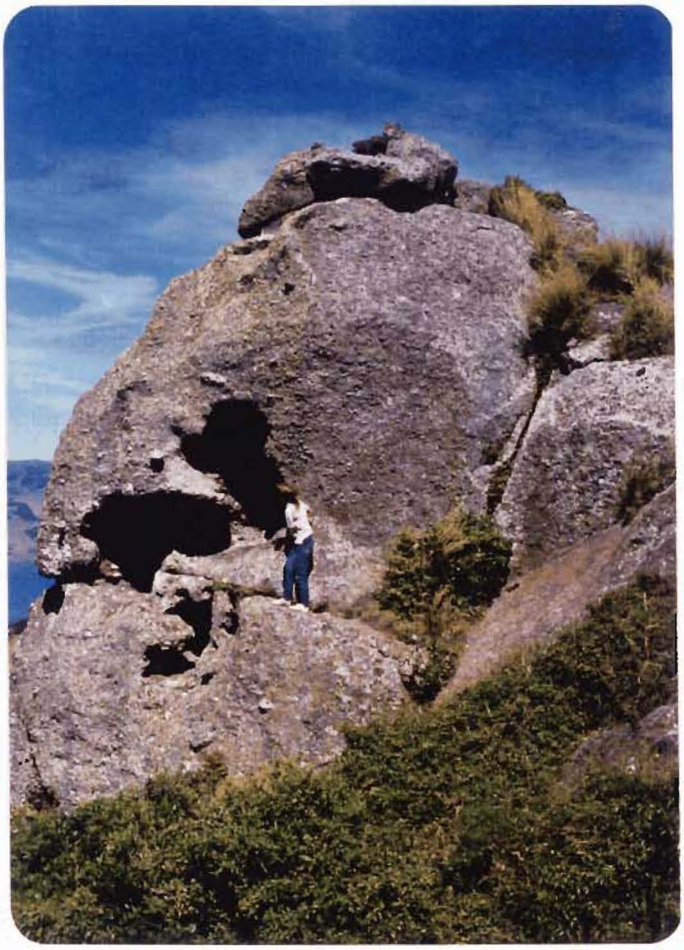


Fig. 2.11 18 m+ thick bedded scoria (probably infills a steep - sided gully) near Peraki Saddle. The generally massive nature of this material makes it effectively impermeable. Joints are visible but are tight and widely spaced. (N37 992 102)

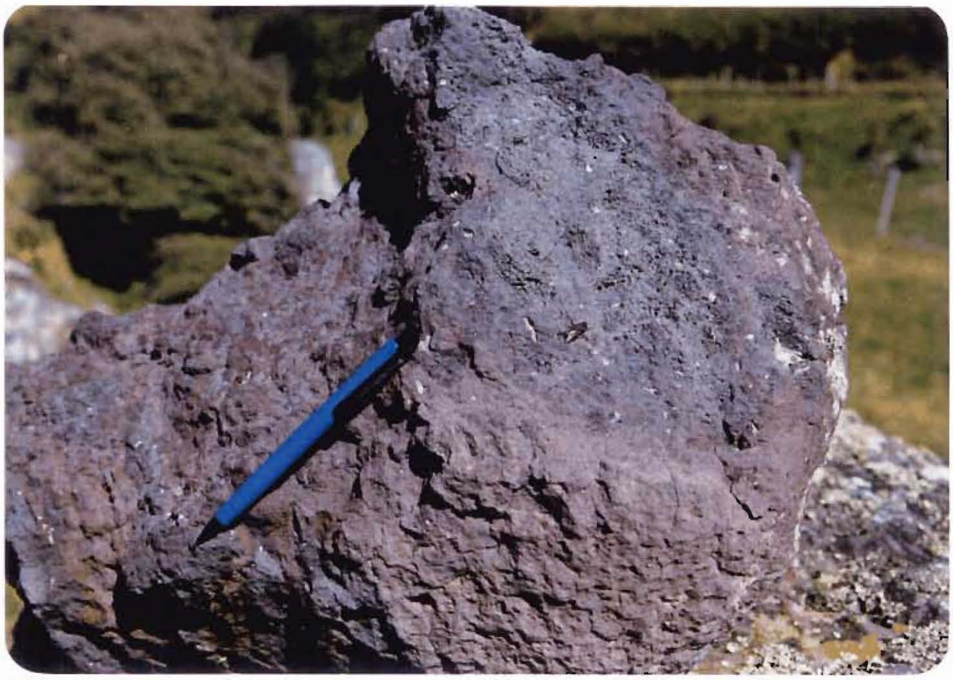


Fig. 2.12 Close up photo of scoria showing grey frothy basaltic clast (to right of pencil top) in fine purplish grey ash matrix. (N37 992 102)

impermeable barrier to lateral water flow (Section 3.2). Table 2.1 summarises the engineering geological and water - bearing characteristics of the trachyte.

2.5 SURFICIAL DEPOSITS

Bell and Trangmar (in prep.) distinguish five types of surficial deposit on Banks Peninsula, these being :

1) In situ primary airfall loess
2) Loess colluvium
3) Mixed deposits of loess and volcanic colluviums
4) Volcanic colluvium
5) Residual regolith

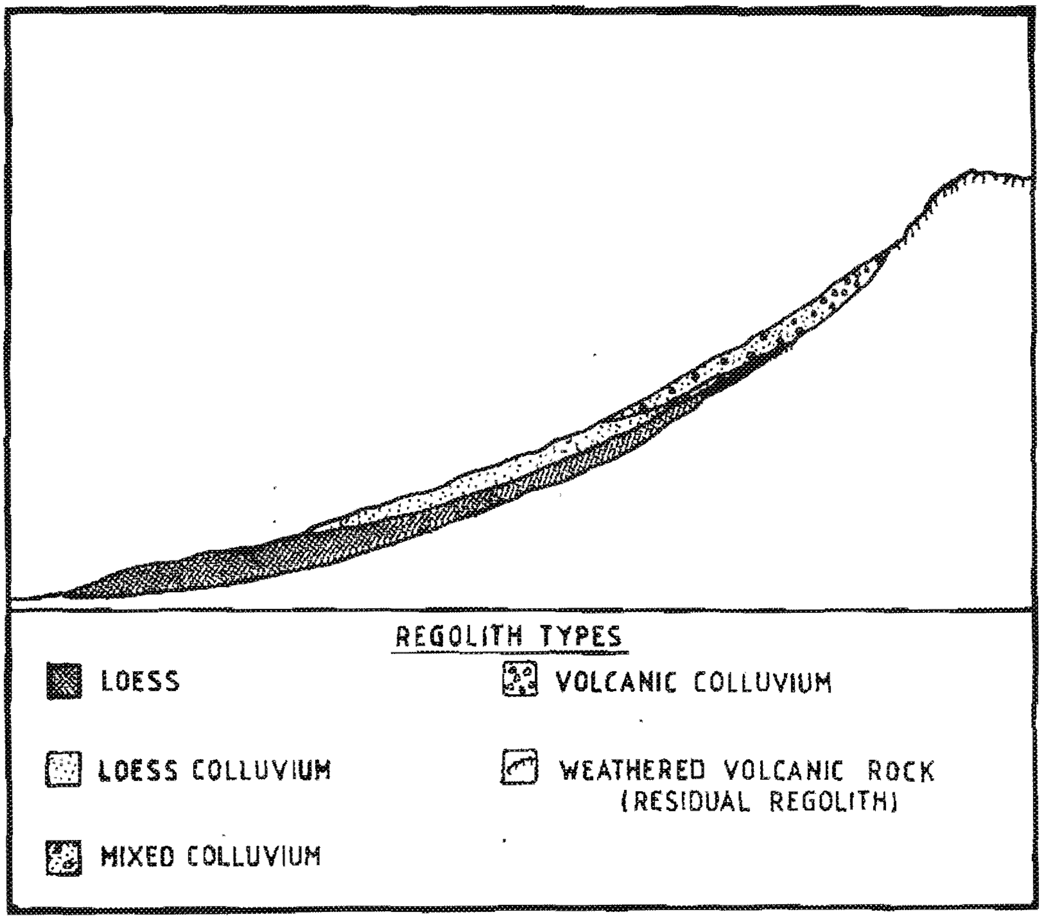


Fig. 2.13 Idealised regolith slope distribution in Akaroa County (after Bell and Trangmar, in prep.).

Fig. 2.13 shows the ideal distribution of the colluvium types on a hillside while Table 2.2 presents generalised engineering geological descriptions and permeability data. Discussion on alluvial material is also presented here.

These material types are of importance in this study because their distribution and in situ permeabilities (Table 2.2) are major factors in determining precipitation infiltration rate and the degree to which groundwater issuing from bedrock aquifers is confined. In situ permeability testing for this study (Appendix 8) has revealed that these deposits possess a general order of decreasing hydraulic conductivity thus: volcanic colluvium, mixed colluvium (usually show a decrease with decrease in volcanic clast component), and loess colluvium. For instance, loess cover is expected to allow slower precipitation infiltration rates and to confine groundwater more effectively than a volcanic colluvium cover.

2.5.1 In Situ Loess and Loess Colluvium

a) Composition

Griffiths (1973) in mapping the loess of Banks Peninsula found Akaroa County to consist of mostly non - calcareous Barrys Bay Loess. In situ (airfall) loess is usually a yellowish brown quartzofeldspathic clayey silt and may show a profile as depicted in Figure 2.14. Distinct horizontally running grey zones are often visible indicating periods of soil formation during lulls in loess deposition.

Loess colluvium is generally composed of the same clayey silt material, but contains up to 10% volcanic rock fragments mixed in during mass movement. Most deposits show distinct though discontinuous layering representing different depositional events.

SURFICIAL UNIT	GENERAL ENGINEERING GEOLOGICAL DESCRIPTIONS (APPENDIX 1)	IN SITU PERMEABILITY (APPENDIX 8) m/s
In Situ Loess	Unweathered to slightly weathered, dry to moist, yellowish brown (orange mottles formed where burrowing exists), massive CLAYEY SILT, (ML).	3.1×10^{-7}
Loess Colluvium	Slightly to moderately weathered, dry to moist, soft to stiff, mottled dark brown and light yellowish brown, massive SILT with some clay and rare fine gravel (ML).	1.3×10^{-6}
Mixed Colluvium	Slightly to moderately weathered, dry to moist, soft to firm, dark yellowish brown, massive SILT with some fine to coarse gravel and clay, OR fine to coarse gravelly SILT with some sand and clay (ML).	1.6×10^{-7} (10% volcanics) 5.1×10^{-7} (25% volcanics) 2.6×10^{-6} (35% volcanics)
Volcanic Colluvium	Slightly to highly weathered, dry to moist, soft to hard, yellowish to reddish brown, SILTY FINE GRAVEL with some sand (GM), OR fine to coarse GRAVEL with some silt and clay (GP).	1.1×10^{-5}

Table 2.2 General engineering geological descriptions and in situ permeabilities for the surficial deposits of Akaroa County.

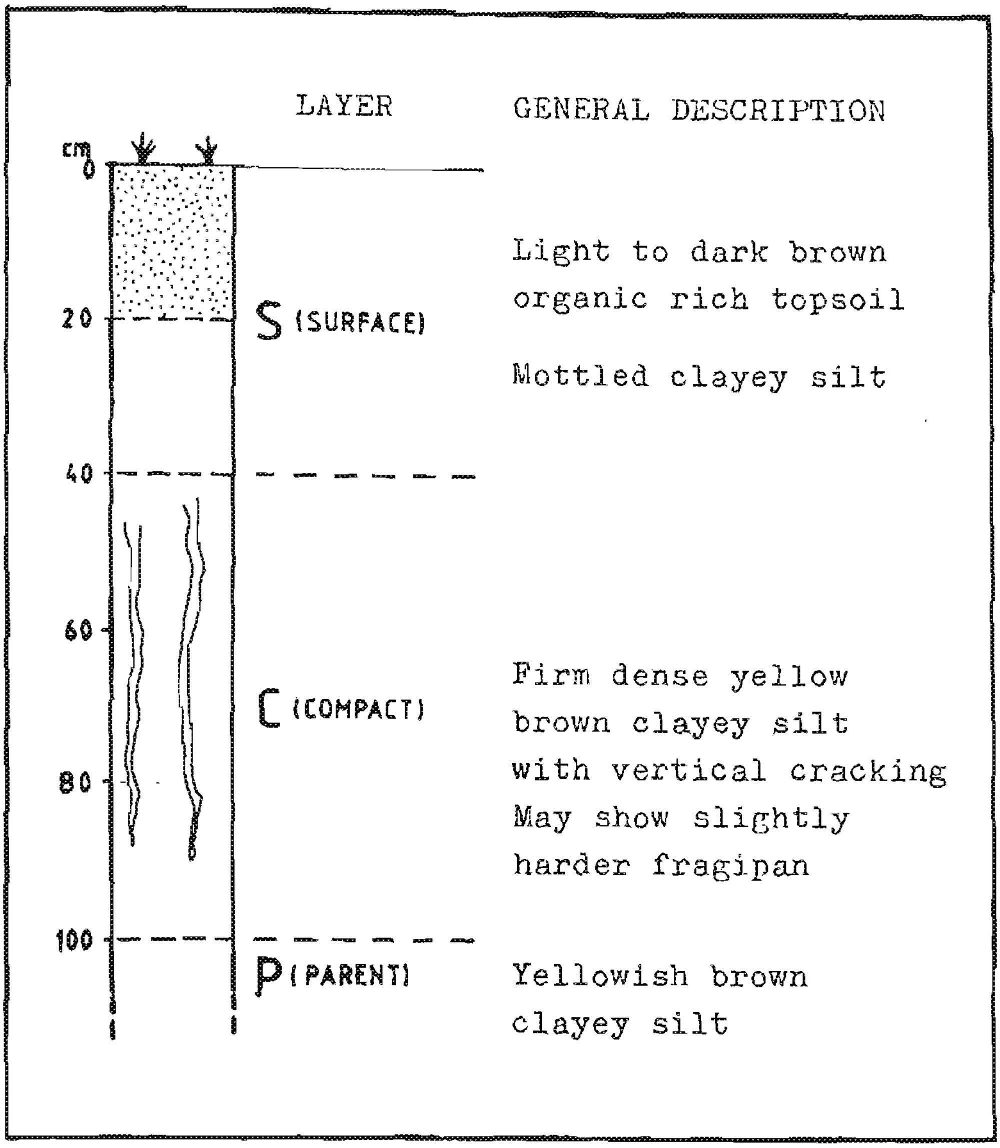


Fig. 2.14 Schematic profile in the loess of Akaroa County (after Evans, 1977).

b) Origin

The greywacke - derived silts originated mainly from Pleistocene glacial grinding. Subsequently deposited on fluvial glacial outwash fans these silts were finally transported by north west winds and deposited as an airfall blanket over the Canterbury Plains and the eroded flanks of Banks Peninsula. Downslope transport of the airfall material by mass movement processes, such as slide - avalanche - flows (Bell and Trangmar, in prep.), has yielded the loess colluvium deposits.

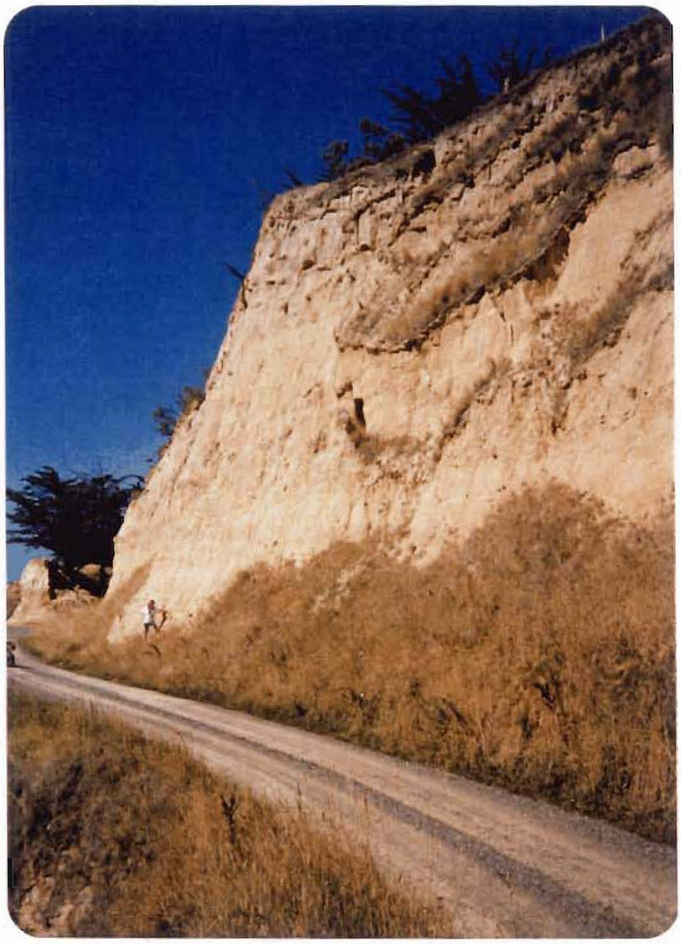


Fig. 2.15 Exposure (approximately 14 m high) of in situ loess on Onawe Peninsula, and about 4 m above sea level. Griffiths (1973) recognises four periods of loess deposition in this outcrop. (Grid Ref. N36 042 162)

c) Distribution

In situ loess has been observed up to 15 m thick near sea level (Fig. 2.15) and declining with increasing altitude. On steep slopes little or no pure loess is found but on the flat ridges or rolling summit tops thicknesses of up to one or two metres are found.

Loess colluvium occurs on shoulders, backslopes, footslopes, and toeslopes with a thickness between 0.5 and 15 m or more.

d) Water - Bearing Properties

Exposure of loess profiles in Akaroa County is mainly restricted to road cuts and escarpments at the head of slide - avalanche - flow failures. Consequently field observation of water flow in in situ loess is limited, but it appears to occur at the loess - bedrock interface, and above the C-layer fragipan where this is developed. Evans (1977) has observed water movement within the P-layer, and Hughes (1970) postulates that water enters this layer through dessication cracks that may or may not extend to the ground surface, or gain direct entrance along the upper margins of the loess where it lies against bedrock. A similar occurrence is suspected in Akaroa County. Figure 2.16 depicts these models for groundwater flow in loess.

Layering (eg. palaeosols) in loess colluvium has a great influence on water flow due to permeability and despersion differences, and contacts between layers often provide discontinuities along which water movement and erosion tunnels can occur.

Tunnel gullying is an erosional feature due to water flow within more dispersive loess layers. Where the depth of loessial material is less than 1 m or where the fragipan is poorly developed gullying may occur directly over the bedrock, and aquifer sources within the bedrock may provide the water source.

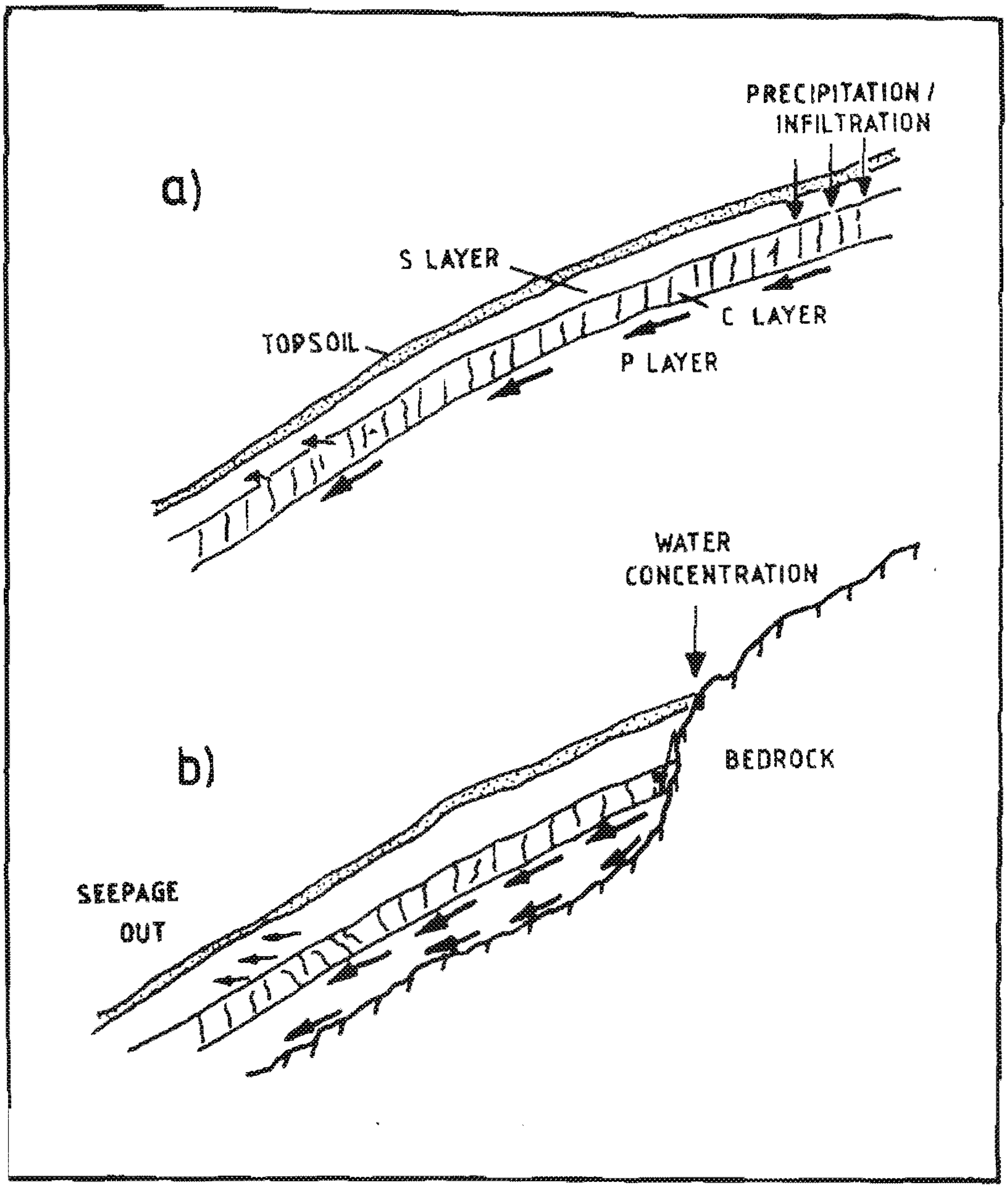


Fig. 2.16 Models for groundwater flow in loess with well developed layering.

a) with direct infiltration of rainwater into profile, and without influence of underlying bedrock (after Evans, 1977).

b) with rainwater concentration at the bedrock interface, in combination with direct infiltation through soil layer and underlying bedrock (after Hughes, 1970).

In situ permeablity testing (Appendix 8) of primary airfall loess and recently slumped loess reveals values of 3.1 x 10^{-7} m/s and 1.3 x 10^{-7} m/s respectively. The more jointed nature of the slumped loess explains the difference.

2.5.2 Mixed Colluvium

a) Composition

Mixed colluvium is loess colluvium mixed with volcanic weathering products derived from upslope (Bell and Trangmar, in prep.). The ratio of loess to volcanic material ranges from 10% to 90% and therefore morphology is highly variable. Colour ranges between yellow brown and dark reddish brown depending on the proportion of volcanic material. The volcanic fragments are fine sands or boulders decreasing in size and abundance with increasing distance from bedrock outcrop.

b) Distribution

Mixed colluvium is found on backslopes and upper footslopes below volcanic rock outcrops, overlying in situ loess, older colluvium, or bedrock. Thicknesses between 0.3 and 3 m occur in Akaroa County.

c) Water - Bearing Properties

Groundwater seepage occurs throughout the mixed colluvium layer, sometimes creating small (up to 40 cm) tunnels within the profile, or at the bedrock interface. Where underlying loess is firm water may perch above this.

Measured permeabilities range between 1.6 x 10^{-7} m/s and 2.6 x 10^{-6} m/s with a trend towards higher permeability with greater volcanic component (Table 2.2), though degree of compaction is also influential. Infiltration through mixed colluvium is expected to be faster than through loess as a consequence of this generally higher permeability and spring - derived surface water is often seen to re - enter mixed colluvium after a short distance.

2.5.3 Volcanic Colluvium

a) Composition

Much steep high ground is irregularly mantled with volcanic colluvium consisting of volcanic - derived material mixed with small amounts (less than 10%) of loess. Where matrix is present colour ranges from reddish brown to brown and becomes lighter as loess content increases. Rock fragments are angular to subangular ranging from gravels to boulders with size generally decreasing away from bedrock outcrop. Commonly observed mantles of rock clasts resulting from rockfalls, topples, or rockslides have been mapped as volcanic colluvium.

b) Distribution

Volcanic colluvium occurs on moderately steep mid - back slopes immediately below the outcrops, and is extremely variable in thickness, ranging up to 1.2 m (for rock - fall, - topple, and - slide material clast size is a major influence on thickness) and thinning away from outcrops. It often overlies weakly weathered volcanic basement or a strongly weathered zone in the upper part of the volcanics.

c) Water - Bearing Properties

Groundwater movement is distributed throughout the colluvium profile but frequently occurs near the bedrock interface. Erosion cavities within the profile may occur when water flow erodes fine grained matrix from between the coarser clasts which subsequently collapse. Such tunnels have been observed up to 30 cm in diameter but are often very small (down to 3 cm).

The gravel texture to many volcanic colluvium materials gives relatively high permeabilities, a figure of

1.1×10^{-5} m/s being gained for one such in situ sample (Table 2.2). Volcanic colluvium is expected to show the fastest infiltration rates of the tested regolith types as a consequence.

2.5.4 Residual Regolith

In situ weathering of volcanic bedrock produces residual regolith often seen as shallow reddish brown silty clay loams with up to 25% subangular weathered gravel and cobble sized volcanic materials. Residual regoliths have been mapped with volcanic colluvium because of their similar permeability properties. Residual regolith occurs on low angle slopes atop ridges at high altitudes where precipitation rates are relatively high. Consequently these materials are considered to act as media for infiltration.

2.5.5 Alluvium

Alluvium deposits exist in the valley bottoms of Akaroa County and consist of well graded silt to coarse gravel sized sediments (mainly volcanic - derived, but with some loess included). Lenses of bluish grey or brown muddy fine sands have been revealed in generally unsuccessful well drives within this area and may provide a permeability barrier to water movement in the coarse alluvium.

2.6 GEOLOGICAL OCCURRENCE OF THE SPRINGS

Groundwater discharge in Akaroa County occurs at springs whose form and distribution are geologically controlled. Discharge may occur directly from bedrock aquifers, but more commonly is through the extensive surficial cover.

2.6.1 Spring Morphology

Springs of two morphologies are observed. Springs showing confined flow issue from materials possessing high permeability, including volcanic breccias and fractured lavas, or regolith in which are present fractures, eroded cavities (Fig. 2.17), or a high coarse size fraction. Considerable spring discharge occurs from some materials, such as homogeneous loess or mixed colluvium, but their permeability is so low that the water is forced to the surface over a large area. The resultant diffuse springs are often seen as green stock - trampled patches on dry hillsides in summer or may show as reedy areas elongated in a downhill direction (Fig. 2.18).

2.6.2 Spring Distribution

Lines of springs often occur at discrete levels tracing lava flow dips and indicating bedrock control of spring distribution. These occur as contact springs (Bryan, 1919) where permeable rock units overlie units of lower permeability, or colluvial springs relating to bedrock - derived water.

Geomorphic benches, often traceable for several kilometres, are commonly associated with spring lineations. Two observations relating to these benches are:

1) They can result from exploitation of basal breccias by weathering leading to collapse of the overlying lavas.
2) Benches are commonly capped by relatively impermeable and erosion resistant beds such as tuff, scoria, or massive lava.

Both observations provide geological factors conducive to the presence of springs and are consistent with field observation. Surficial material often mantles the benches confining related groundwater, but may thin at the bench edge where associated scarps fall away allowing escape of the water as springs. Consequently many springs lie close to bench edges. Springs in the middle of some benches may have migrated back from the scarp top due to piping erosion of surficial material.

Fig. 2.17 Spring emerging from erosion cavity in loess in confined flow (N37 098 095).

Fig. 2.18 Springs (many emerging in diffuse flow from mixed colluvium) on hillside in French Farm appear as green patches and reedy areas elongated in a downhill direction in mid summer. Note proximity of springs to ridge top (Rocky Peak is the highest point in this photograph (N36 015 125)).

At lower altitudes, where surficial deposits are generally thicker, the evidence for bedrock control of springs is less obvious and distribution is often determined by the presence of permeability barriers (eg. fragipan layers in loess) or higher permeability zones (eg. volcanic clast - rich zones in mixed colluvium) within the material itself.

2.6.3 Geological Classification of Springs

For this study springs are classified according to the geological materials from which they are observed to flow. This material is not necessarily the water source. For instance, a bedrock origin is suspected for much of the water that emerges as springs in colluvial material. Spring types in order of abundance are thus: mixed colluvium, volcanic colluvium, loess, volcanic bedrock (jointed lavas and breccias), and alluvium.

2.6.4 Springs From Volcanic Bedrock

Though the Akaroa Group lavas are considered to be the main aquifers of the area, the extensive surficial cover means that very few bedrock springs are observed. Bedrock springs issue from fractured lavas and brecciated layers where these overlie relatively impermeable beds (Figs. 2.19 - 2.22) such as those listed in Section 5.2. Red tuff is the dominant perching layer in many bedrock springs and most occur in the steeper high altitude regions where less surficial cover exists.

2.6.5 Springs in Mixed and Volcanic Colluvium

Mixed and volcanic colluvium springs are most common due to the extensive nature of these regolith types at the higher elevations where most recharge occurs (Section 5.4). These springs derive their water from bedrock aquifers (the water being confined until the colluvium cover allows exit to the ground surface) and from direct precipitation - infiltration into the surficial material.

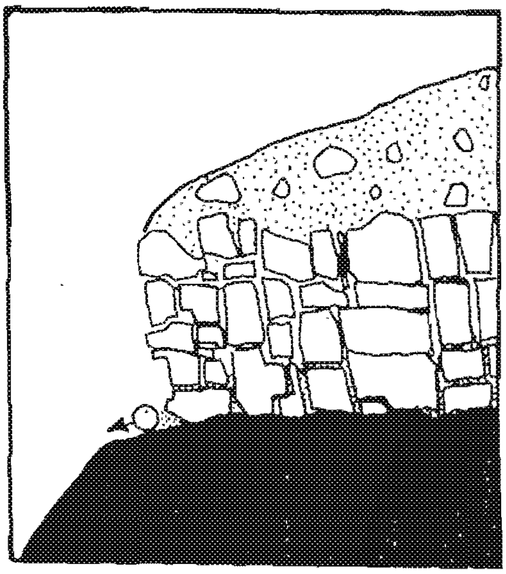


Fig. 2.19 Schematic diagram: spring issuing from jointed lava where this overlies tuff layer (solid black in diagram). Mixed colluvium overlies the jointed lava.

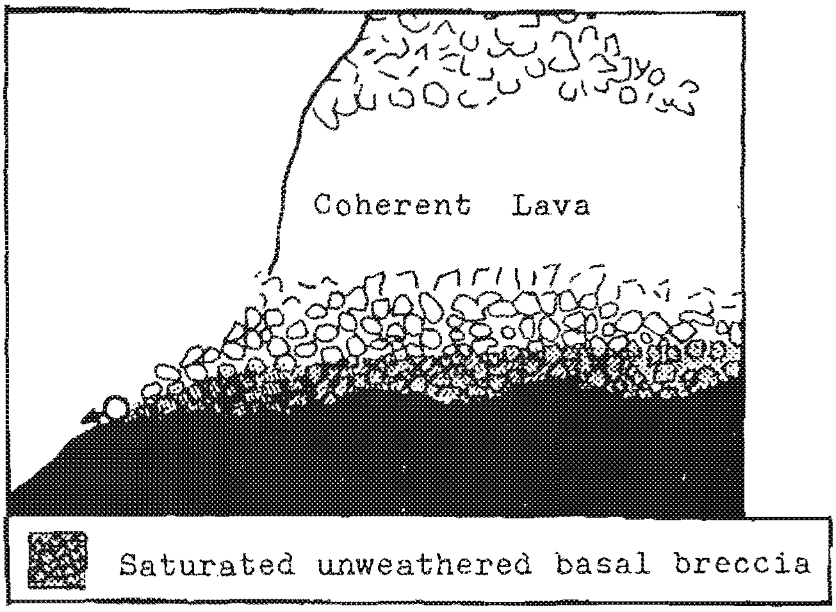


Fig. 2.20 Spring emerging from unweathered basal breccia where this overlies relatively impermeable layer, eg tuff.

Fig. 2.21 Bedrock spring flowing from jointed basaltic lava where this overlies red tuff layer. Mid summer flow is shown (about 1.5 litres per minute) at this French Farm spring. (N36 014 128).

Fig. 2.22 Water exiting from slightly weathered basal breccia overlain by volcanic colluvium. This water is perched above unjointed lava. (N36 021 150).

Springs occur where groundwater rises to the ground surface due to input of water from volcanic beds (Fig. 2.23), or where surficial cover thins allowing exit of perched water near the bedrock interface (Fig. 2.24). Many springs associated with geomorphic benches are of the latter type and often relate to a nearby outcrop of tuff or massive lava.

Both confined and diffuse springs emerge from these colluvium types. Confined springs exit where there is fracturing or an abundance of volcanic clasts. Small tunnel features (up to 40cm in diameter) may allow ready exit of groundwater (Fig. 2.25). Diffuse springs are very common in mixed colluvium especially where slope angles and volcanic clast content are low.

2.6.6 Springs in Loess

Fewer springs emerge from loess than from mixed or volcanic colluvium. Nearly all loess springs lie below the 300 m contour and consequently are remote to the main recharge zone which occurs in the summit region. Recharge at these lower levels is less because of lower rainfall (Fig. 1.3), and the slower infiltration rates that occur in the loess when compared to mixed or volcanic colluvium. These factors may explain the generally low discharge (nearly all flow at less than 2.5 litres per minute) of mapped loess springs.

Springs emerging through loess tend to be diffuse because of the material's relatively low permeability (10^{-6} to 10^{-7} m/s) and generally low slope angles (most lie between 5 and 15 degrees). More confined springs occur where fracturing or tunnelling are present. Bedrock derived water may travel long downslope distances before breaking through the loess cover. Water moves slowly along vertical permeability barriers such as the C-layer fragipan, or the loess - bedrock boundary, to emerge as springs where these barriers intersect the ground surface or where the water

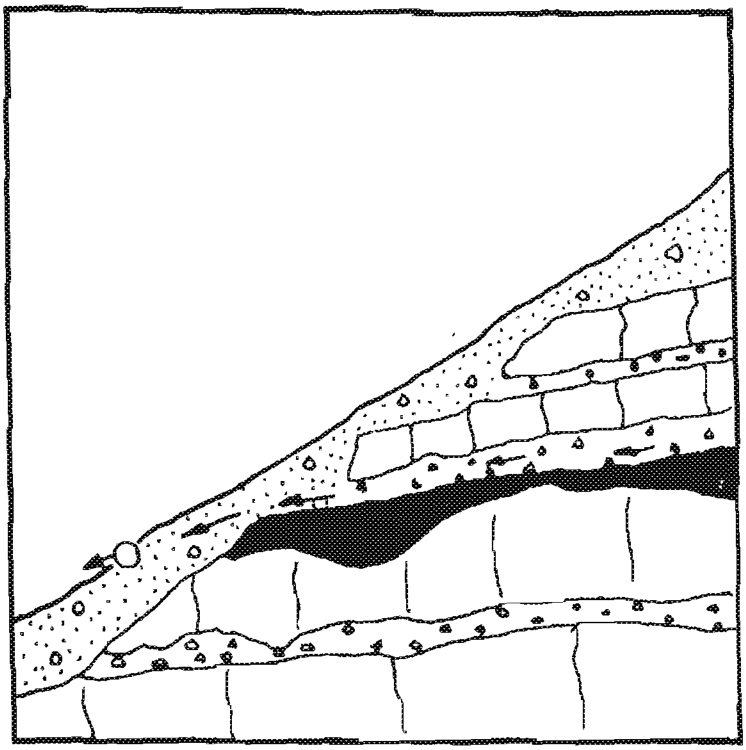


Fig. 2.23 Mixed or volcanic colluvium spring due to input of water from bedrock aquifer. Arrows show flow path of water from basal breccia overlying tuff bed (solid black) out into colluvium.

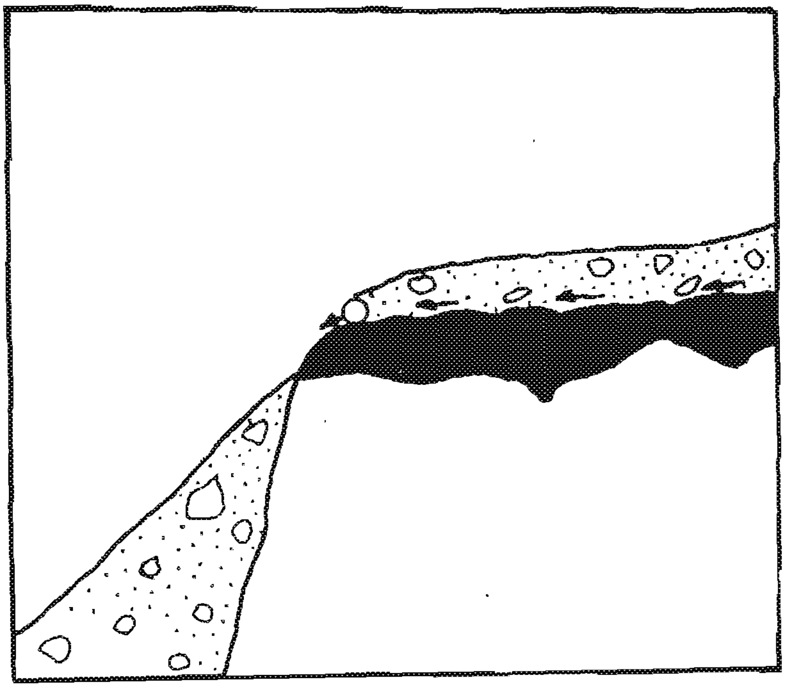


Fig. 2.24 Mixed or volcanic colluvium spring where colluvium thins over change in slope in underlying volcanics. Arrows depict possible flowpath through colluvium above tuff layer (solid black).

Fig. 2.25 Mixed colluvium spring exiting through 20 cm diameter erosion cavity in French Farm Valley. Confined flow occurs. Note composition of mixed colluvium - approximately 20% subangular basalt clasts in a loess matrix at this locality. (N36 998 131)

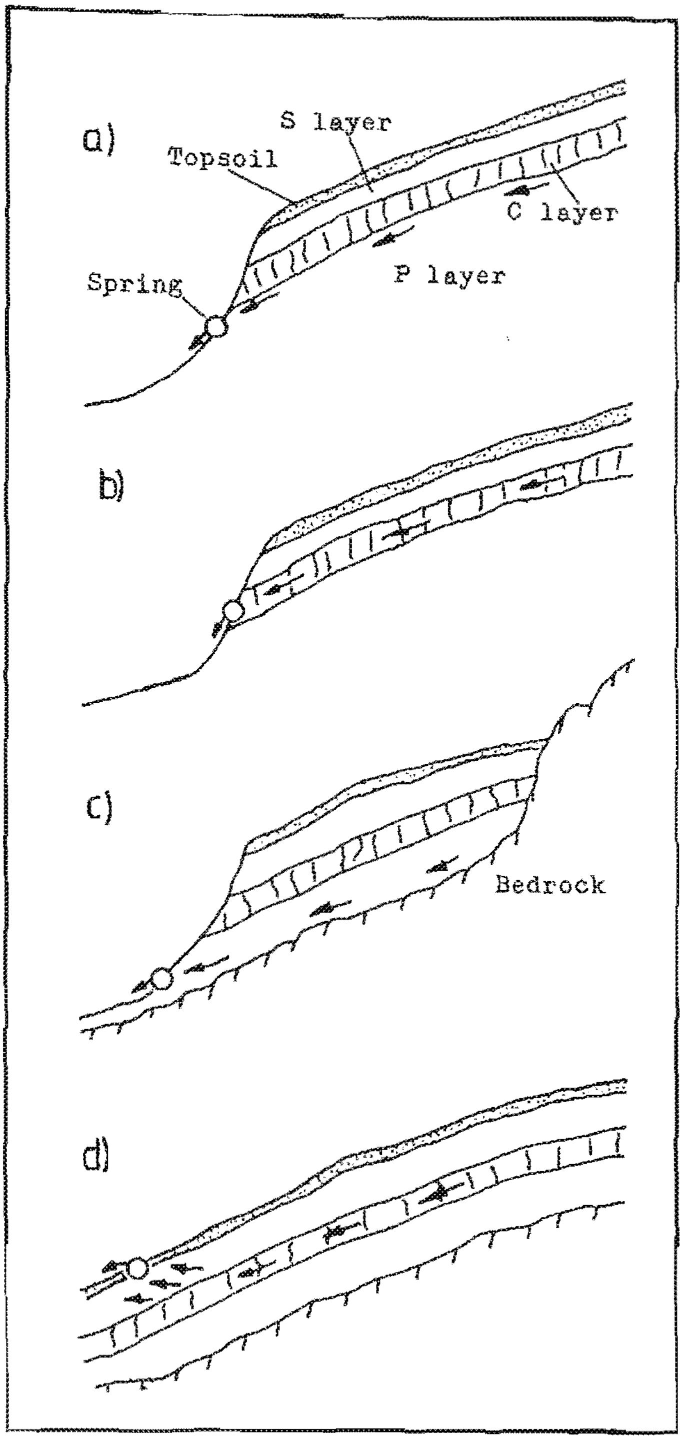


Fig. 2.26 Loess spring models.

a) spring occurs where water flowing in loess P layer intersects ground surface. Confined springs result when tunnels develop.

b) spring due to water perched above C layer fragipan.

c) loess spring at bedrock interface.

d) diffuse spring where water seeps to surface from, for example, above the C layer.

levels rise to the ground surface. Models for springs emerging from loess based on observations by Evans (1977), Bell and Trangmar (in prep.), and this author are depicted in Figure 2.26.

2.6.7 Springs in Alluvium

Springs occurring in alluvium are very uncommon. Where present they appear to be depression springs occurring in hollows thought to be disused stream channels. (Fig. 2.27).

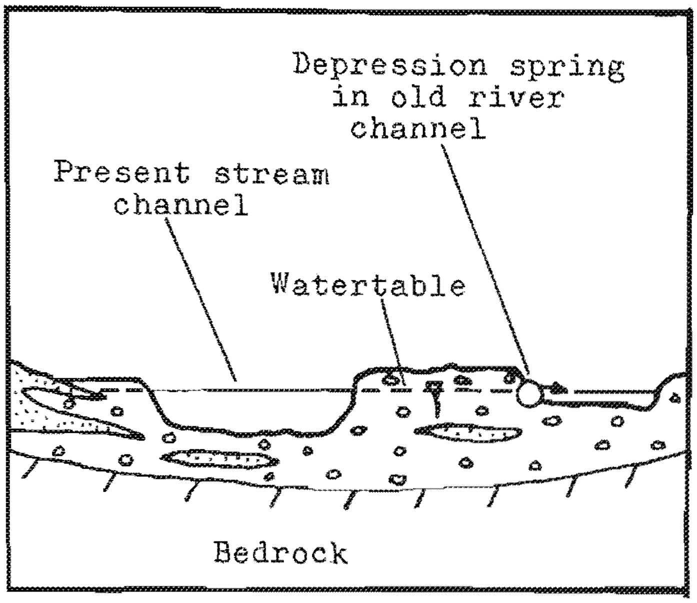


Fig. 2.27 Depression spring in alluvium exiting into old disused river channel. Alluvium shows loess - rich silt interbeds below which possible artesian conditions may exist (Yetton, 1983).

2.7 THE ROLE OF SPRINGS IN MASS MOVEMENT

Water is the dominant triggering mechanism for slope failures in the surficial cover of Akaroa County. Seeps and springs that serve as groundwater exits are indicators of internal water pressures, but they themselves are not necessarily the cause of mass movements. Springs uphill from a landslide can serve as sources of surface water that can infiltrate back into the slide material and contribute to renewed instability. If however they exit within the slide zone or downhill from it they can contribute to stability instead. Less pore pressure builds up when the groundwater is allowed to escape than when the groundwater exits are blocked.

The La Clare landslide (Hill, 1985) in Akaroa township is a case in point. This slide occurred in loess partially as a result of burial of three ephemeral springs beneath a road embankment resulting in saturation of the fill and landslide material beneath. Increased loading and decreased strength lead to eventual failure.

CHAPTER 3

HYDROGEOLOGICAL STUDIES ON SPRINGS IN FRENCH FARM

3.1 INTRODUCTION

The springs of Akaroa County occur on the eroded crater slopes surrounding Akaroa Harbour, and on the more gently dip sloping outer flanks of the volcano. Where valleys are developed on the inner (crater) slopes lava flows generally dip up valley, while on the outer slopes lava flows dip down valley. It was theorised that this configuration would result in noticeable differences in spring occurrence. Consequently an area of each type has been studied with a view to determining the hydrogeological and recharge models, and management recommendations, appropriate to the springs of the whole of Akaroa County.

The first area, situated on the inner slopes of the volcano, is French Farm Valley (including French Hill on the crater rim), while the second is Pigeon Bay Valley on the volcano's outer flanks. This chapter presents the findings from French Farm, and Chapter 4 relates to Pigeon Bay Valley.

3.2 SETTING

French Farm Valley lies on the north - western side of Akaroa Harbour 4 km from Barrys Bay and 15 km from Akaroa township (Fig. 3.1). The valley is bounded by two prominent ridges that fall towards the harbour from the peaks of Saddle Hill (841 m) and French Hill (815 m), and the ridge that joins the two which reaches a low point at Wainui Pass (550 m).

Two main streams drain into French Farm Bay from the

<u>Fig. 3.1</u> Locality diagram for the French Farm study area (smaller box outlines the French Hill study area). Map is section of NZMS 260, N36, 1:50,000 Map.

Numbers refer to studied springs, ie.

1 Abattoir Springs
2 Nursery Spring
3 Lower Loess Spring
4 Otehore Spring
5 Saddle Hill Spring

east - west trending valley. The larger French Farm Bay Stream (Fig. 3.1) shows measured flow rates betwwen 20 and 360 litres per second (Appendix 10) at the Wainui Road bridge. This stream drains most of the valley, and has two large tributaries with spring sources near to the peaks of Saddle and French Hills (Fig. 3.2, in map pocket). The second main stream originates in gullies between Greenmeadows and Sunnybrae and enters French Farm Bay just south of French Farm Bay Stream. These streams are dominantly spring fed during dry periods.

French Farm Valley lies across the path of moisture - laden southwesterly winds that are funnelled up Akaroa Harbour. Unofficial readings kept by Bill Weir of Otehore record a mean annual precipitation of 1413 mm (Table 3.1a, Fig. 3.3a) over the 1969 - 84 period. For the study period from September, 1984 to August, 1985 a precipitation of 965 mm was recorded (Table 3.1b, Fig. 3.3b). This is expected to be greater at the higher altitudes of the valley head and lower near sea level (Fig. 1.3).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
Mean (mm) 1969-84	88	64	80	109	140	144	185	184	98	127	75	95	1413

Table 3.1a Mean rainfall data for French Farm (observed at Otehore, Grid Ref. N36 006 135) from recordings between 1969 and 1984.

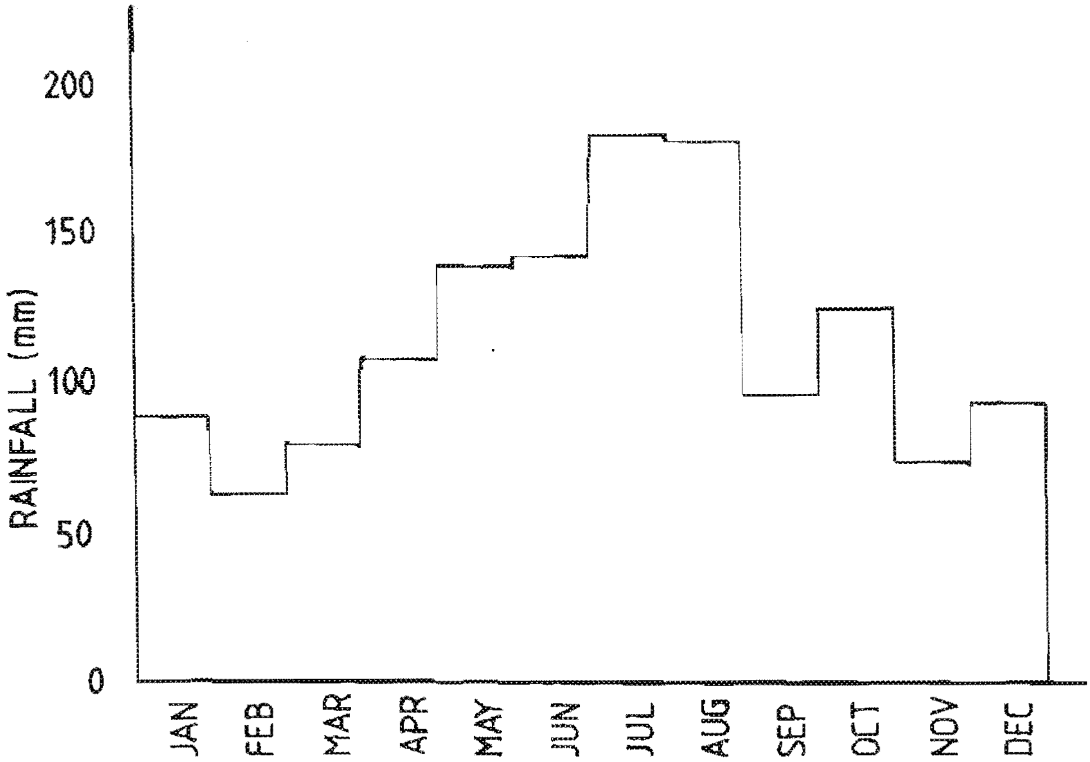


Fig. 3.3a Histogram showing mean monthly rainfall (for 1969 - 1984) as recorded at Otehore (N36 006 135).

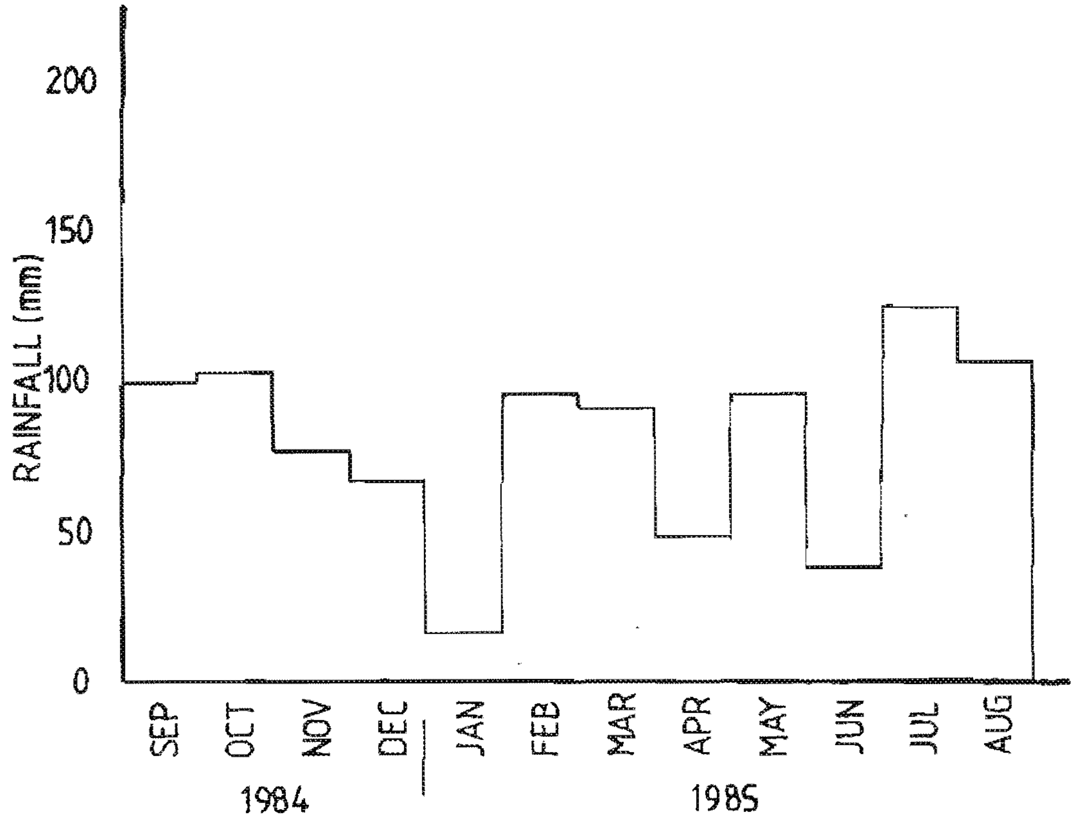


Fig. 3.3b Histogram of monthly rainfall for French Farm as recorded at Otehore over study period (September, 1984 to August, 1985).

Month	1984 Sep	Oct	Nov	Dec	1985 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Tot.
Rain-fall (mm)	98	102	77	66	17	96	91	49	96	38	127	108	965

Table 3.1b Rainfall observed at Otehore during study period.

Landuse is diverse due to a generally mild climate, with few frosts at low altitudes, and fertile lower slopes. Sheep and cattle fattening predominates but a protea nursery and deer farm are making an impact in the area. Numerous holiday homes near the valley base show this to be a popular recreational area.

3.3 GEOLOGY AND GEOMORPHOLOGY

The results of geological and hydrological mapping relevant to the springs of French Farm are recorded on Fig. 3.2 (in map pocket). The lower slopes of French Farm Valley exhibit poor volcanic bedrock exposure due to surficial cover, and most outcrop occurs above 500 m. Limited exposure does however show a general pattern of westerly dipping basic lava flows with subordinate intercalated pyroclastics on a basement of trachyte breccia (exposed in the wavecut platform).

3.3.1 Bedrock Geology

The lavas consist predominantly of fresh to slightly weathered, very strong, dark grey, phyric to aphyric, medium to finely crystalline, basaltic rock. Falloon (1982) has distinguished flows of hawaiite and mugearite near French Hill and Saddle Hill, with mugearite close to Pulpit Rock. On the southern valley side flows dip between 4 and 8 degrees to the south west. Similar magnitude dips occur on the French Hill side though these trend to the north west. Near the summit beds are essentially flat lying.

Most volcanic exposure is unbrecciated lava centres, but red ash beds, and breccias and scoria beds showing various degrees of weathering are often seen at spring sites.

Rocks of the coastal section are cut by numerous intersecting trachyte dykes of the Akaroa dyke swarm. Extensive jointing of both the dykes and the lower basalt beds is probably due in part to isostatic rebound caused by erosion (Falloon, 1982).

The dominant geological feature of French Farm is the aegerine - augite trachyte intrusion that forms Pulpit Rock (Fig. 3.4). This intrusion stretches for 600 m across the upper part of French Farm Valley (Fig. 3.2, in map pocket). The stream occupying the valley floor has cut deeply into the moderately weathered trachyte dividing the exposed portion into two sub - equal parts but not exposing the base. Pulpit Rock is the 75 m high southern exposure and shows a prominent sub - vertical jointing suggesting a dome - like form to the original intrusion. Block jointing near the summit of Pulpit Rock is probably due to tensive forces during cooling of the trachyte magma (Falloon, 1982). These joint sets are however tightly closed making this intrusion effectively impermeable. Several springs occur at the boundary of Pulpit Rock and the lavas it has intruded and a possible model for the presence of these springs is presented in Figure 3.5.

3.3.2 Surficial Deposits

The distribution of the various surficial deposits is shown on Figure 3.2. Loess predominates at lower levels (generally below 250 metres) with mixed and volcanic colluviums move common at intermediate and higher altitudes (between 250 and 800 metres). Surficial material often

Fig. 3.4 View looking south west towards Pulpit Rock (N36 997 132, centre of photo). Lava flows dip from left to right on photo.

Key: A - position of springs of type in Fig. 3.5

B - line of springs (incl. Saddle Hill Sp.).

C - north western extent of intrusion.

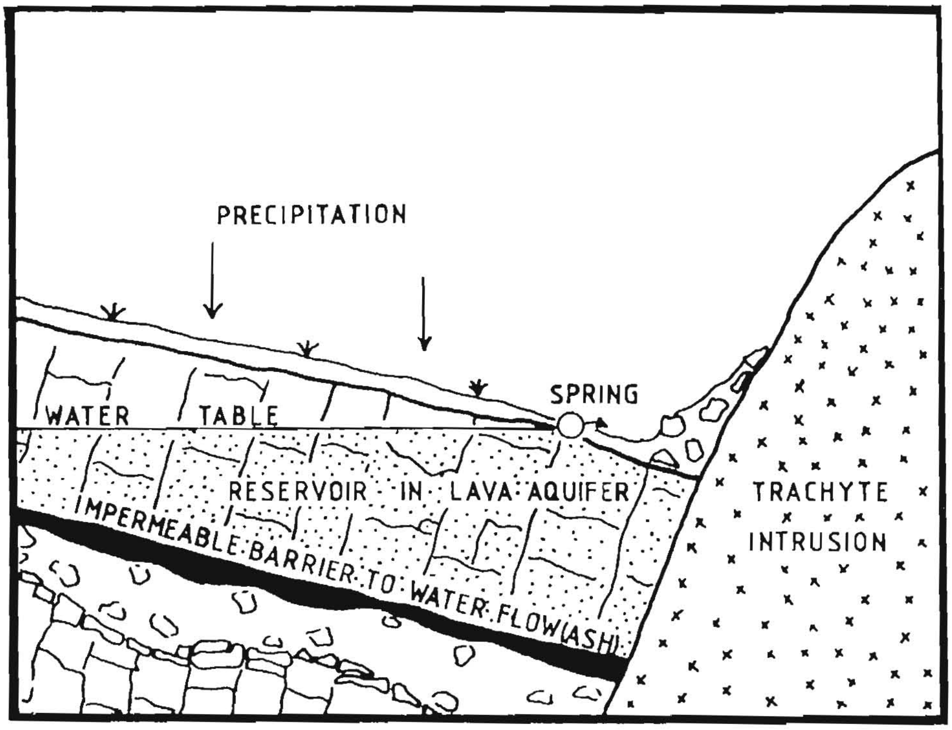


Fig. 3.5 Model for existence of springs on eastern side of Pulpit Rock. Wedge shaped water body forms in lava that dips to west, due to permeability barriers provided by underlying ash and intrusion. Spring issues through overlying colluvium.

confines groundwater derived from the volcanic beds causing springs to emerge further downhill than would be expected.

3.3.3 Geomorphology

French Farm Valley rises steeply to an altitude of between 550 and 815 metres over a distance of only 3.5 km from the Valley base at sea level (Fig. 3.6).

The lower valley floor extends for 1 km through alluvial and loess flats. The valley then rises steeply through mixed colluvium mantled ridges into a region of alternating resistant lava cliffs and flat benches (Fig. 3.7). This region is deeply incised where significant streams exist. Higher slopes are generally steep and rugged due to truncation by joint - controlled erosion of the westward dipping lava flows. The prominent ridges bounding the study area are intermittently stepped by lava cliffs but are generally smooth because of the covering mantle of surficial materials (mainly mixed colluvium).

3.4 THE SPRINGS OF FRENCH FARM

3.4.1 GENERAL

Distribution

Over 200 springs have been mapped in French Farm (Fig. 3.2). Springs are concentrated on the upper slopes close to the major ridgetops of the area. For instance, the 250 metre contour has been chosen to divide the study area into two similarly sized regions that can be used to statistically compare the occurrence of springs on upper and lower slopes. This division approximates the transition from virtually no bedrock outcrop (due mainly to loess and loess - derived mantle) to the region where alternating lava cliffs and intermediate benches occur with a subsequent increase in outcrop. 50% of the mapped area and 73% of the springs lie above this elevation. This reflects greater recharge due to higher rainfall (Fig. 1.3) and generally

Fig. 3.6 View looking into French Farm Valley from the Summit Road. The two highest points are Saddle Hill (841 m, on the left) and French Hill (815 m). Pulpit Rock is shown by the "P".

Fig. 3.7 View of French Hill (N36 992 157) from near Rocky Peak showing lava benches. "F" is the postion of the French Hill Spring.

faster infiltration rates (due to more bedrock exposure and more permeable surficial materials) at these altitudes.

The relative significance of the various types of springs is summarised in Table 3.2. Springs emerging from

Type	Loess	Mixed Colluvium	Volcanic Colluvium	Bedrock	Alluvium
Number of springs	45	97	57	29	1
% of Total	20%	42%	25%	13%	< 1%

Table 3.2 Relative abundance of various spring types as mapped in French Farm.

mixed colluvium predominate followed by volcanic colluvium and loess colluvium springs. Only 13% of springs emerge directly from bedrock (including brecciated layers and jointed lavas) reflecting the extensive surficial cover. Most loess - derived springs occur below the 250 m altitude while most mixed and volcanic colluvium derived springs are above this level. Almost all bedrock springs lie in the steeper country greater than 250 m above sea level.

Spring numbers existing on all slope aspects are sub - equal, this probably reflecting the low dip of the relatively impermeable unjointed lavas and intercalated pyroclastic beds which are the major influence on spring distribution in this area. Springs commonly occur at changes in slope and are often related to lava benches (Fig. 3.7).

<u>Spring Discharge Magnitude and Variability</u>

Table 3.3 summarises the percentages of springs that

occurred within selected flow rate ranges (Appendix 3) when they were mapped during the summer period. It is clear that

Flow type	Low	Medium	High
Discharge range (litres/minute)	< 2.5 l/min	2.5 - 15 l/min	> 15 l/min
Number of springs	136	81	12
% of Total	60%	35%	5%

Table 3.3 Relative abundance of springs occurring in the various discharge ranges (APPENDIX 3) in French Farm when mapped in the summer of 1984 - 85.

the majority are very small with flows less than 2.5 l/m. Only 5% of the total are high flow springs and about three quarters of these lie above the 250 m contour. Most of the lower altitude springs are low flow reflecting less recharge at this level. A less broken surficial layer (mainly loess) and more consistent slope angle (generally varying between 5^{o} and 15^{o}) may mean groundwater is more effectively confined and lost directly to the sea from these slopes.

Six French Farm springs have been studied in some detail. Their position and some particulars are presented in Table 3.4. The discharge of five of these has been monitored for a one year period. The results for four are plotted with rainfall data on Fig 3.8 (the Abattoir spring is dealt with in Section 3.5).

Spring discharge shows a seasonal trend with a general decrease from spring to autumn followed by a short - lived increase due to significant recharge in July. Otehore Spring shows an erratic flow rate which probably results from rapid response due to storm events in a nearby catchment area. The Lower Loess Spring was dry for most of

Spring	Grid Reference NZMS 260	Altitude m	Max Flow Rate l/min	Min Flow Rate l/min	Type	Isotope Reading	
						^{18}O	D
Lower Loess Spring	N36 024 150	120	0.75	0	Loess		
Nursery Spring	N36 005 147	270	40.2	7.3	Mixed Coll.	-7.6	-50.7
Otehore Spring	N36 006 132	280	66.0	16	Vol Coll.		
Saddle Hill Spring	N36 993 128	580	12.0	Drip	Vol Coll.		
French Hill Spring	N36 993 154	700	–	–	Bedrock	-8.0	-51.7
Abattoir Spring 1	N36 989 160	620	857	18.0	Mixed Coll.	-7.9	-50.2

Table 3.4 Summary table of data from six French Farm springs.

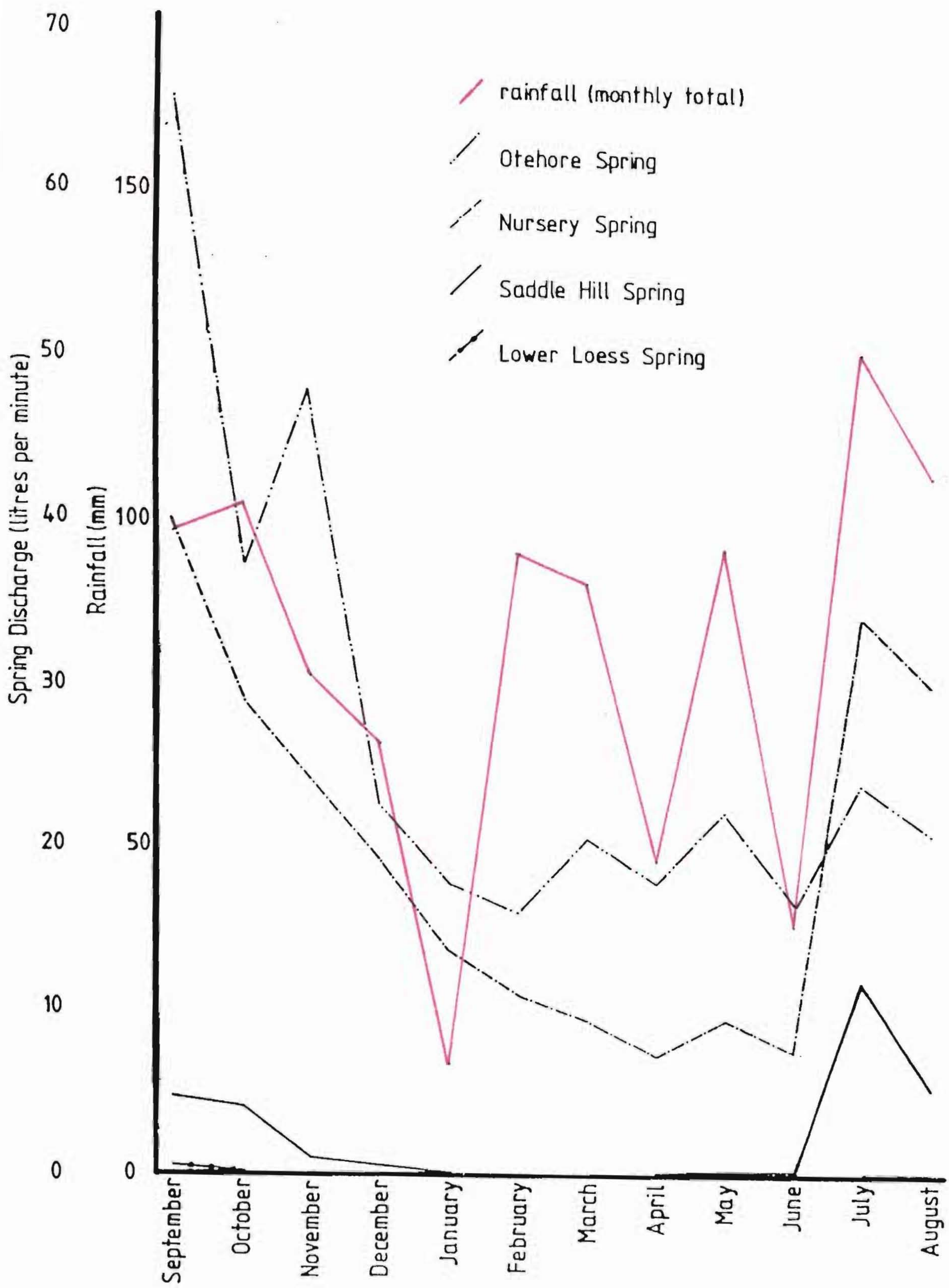


Fig. 3.8 Spring discharge / rainfall (Otehore) for four French Farm springs as measured between September, 1984 and August, 1985 (APPENDIX 9).

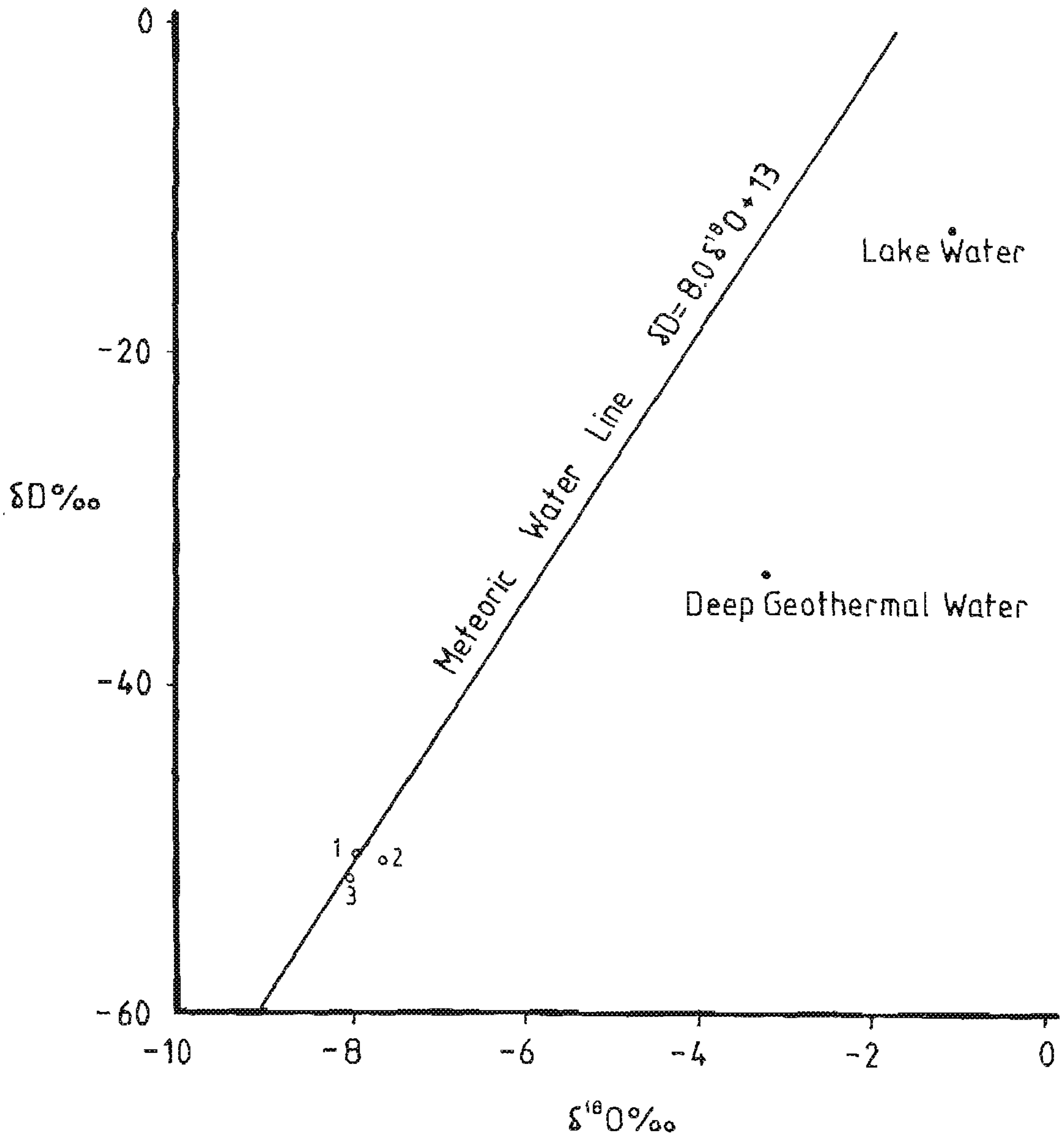


Fig. 3.9 Plot of deuterium and oxygen-18 contents for water samples taken at three springs within the French Farm study area. Note the proximity of the samples to the N.Z. Meteoric Water Line. Lake water and deep geothermal samples are from Stewart and Taylor (1981) and are plotted for contrast. Sample numbers represent:

1 Abattoir Spring
2 Nursery Spring
3 French Hill Spring

the study period due to relatively little precipitation at this low altitude and a storage capacity in the associated aquifer that is insufficient to maintain year - round flow.

Recharge

Oxygen-18 and deuterium compositions of the Abattoir #1, French Hill, and Nursery springs lie very close to the Meteoric Water Line (Fig. 3.9) which is typical of New Zealand rainwater. This is consistent with a direct precipitation - infiltration recharge source for the French Farm spring waters (see APPENDIX 4 for reasoning).

Under natural conditions an aquifer is in a state of dynamic equilibrium and the volume of spring discharge from the aquifer will reflect the amount of recharge occurring. Consequently, it is possible to test whether precipitation is the only influence on recharge by plotting a graph of monthly rainfall (from Table 3.1) against spring discharge for, for example, the Nursery Spring (Fig 3.10). A general trend towards increase in spring discharge with increase in monthly rainfall is evident, but scatter of the graphed points indicates that spring recharge fluctuations are affected by factors other than precipitation alone. Temperature and wind fluctuations (which influence evapotranspiration rates) are suspected to be contributing factors. In combination these influences on spring recharge can provide an adequate explanation for the seasonal discharge pattern previously described.

Water Quality

Table 3.5 summarises chemical analysis results for three French Farm springs (for full analyses see Appendix 5). Observations with respect to potable water quality can be made thus:

1) All waters tested are suitable for drinking water sources.

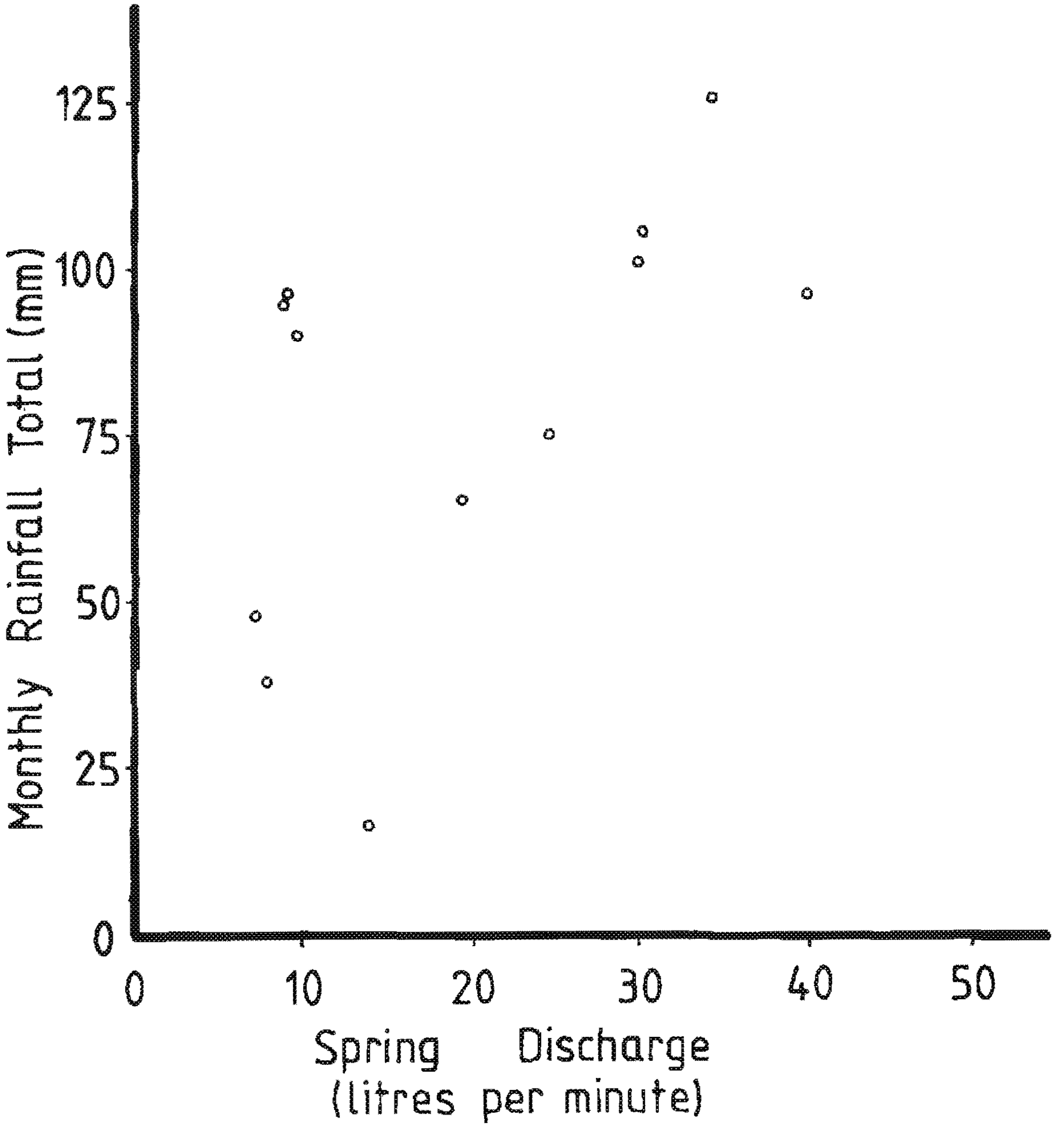


Fig. 3.10 Graph of monthly rainfall data (as measured at Otehore) against spring discharge for the Nursery Spring (APPENDIX 9).

Spring	Sample Number	Grid Reference NZMS 260	pH	Aerated pH	Turbidity (NTU units)	Nitrate Nitrogen g/m^3	Chloride g/m^3	Sodium g/m^3	Magnesium g/m^3	Calcium g/m^3	Iron g/m^3	Hardness (as $CaCO_3$) g/m^3
Nursery Spring	KB310	N36 005 147	6.6##	7.9	0.5	0.8	19	16	1.9	7.5	0.10	27
French Hill Spring	KB309	N36 993 154	6.6##	7.7	1.0	0.6	12	9	0.8	5.7	0.26*	18
Abattoir Spring	KB308	N36 989 160	7.0#	7.9	1.2*	0.9	14	12	4.1	8.5	0.21*	38

This sample does not comply with the following N.Z. standard requirements:

\# Outside desirable range
\## Outside maximum range
* Exceeds lower guideline limit
** Exceeds upper guideline limit

Table 3.5 Summary table of chemical analysis results for three springs in the French Farm study area.

2) Slight acidity (especially of the Nursery and French Hill springs) would probably lead to corrosion of metal water supply fittings.

3) The turbidity value for the Abattoir #1 Spring exceeds lower guideline limits of the New Zealand Standards for Drinking Water (APPENDIX 5). This may be due to exit of the spring from mixed colluvium containing silt and clay. No discolouration is observed however.

4) Iron content for the French Hill and Abattoir springs exceeds lower guideline limits for New Zealand Standards but does not exclude these waters from human consumption.

5) Aluminium content of the French Hill Spring exceeds Standards guidelines (APPENDIX 5), and though this should not be physiologically detrimental to human beings, it may lead to deposits in a reticulation system.

Chemical, isotope, and geological data is available for the French Hill and Nursery springs. This information allows interpretations to be made with respect to recharge area and subsurface flowpaths leading to these springs (see Appendices 4 and 5 for reasoning). A precipitation - infiltration recharge model is assumed in making these interpretations.

3.4.2 The French Hill Spring

The French Hill Spring (Grid Ref. N36 993 154) generally flows at greater than 15 litres per minute and emerges from an open jointed basalt flow where this overlies a more massive lava. It occurs at an altitude of 700 m on the south east facing slopes of French Hill (Figure 3.16 shows the equivalent spring on the north west side of French Hill, denoted by an "A").

The closeness of this spring to its recharge area is indicated by the proximity of its plotted oxygen-18 and deuterium contents to the regional (Akaroa County) regession lines on the isotope/altitude graphs (Figs. 3.11, 3.12). A maximum altitude of recharge of 815 m (the summit of French Hill) is implied, with recharge occurring at all levels between the summit and the spring. Percolation of precipitation water through the soil layer developed on the dominantly volcanic colluvium mantled recharge area is confirmed by a relatively low pH. This acidity results from absorption of carbon dioxide, trapped in the soil layer, by the infiltrating waters.

A subsequent short bedrock flow path is indicated by high iron content but moderately low sodium/ magnesium/ calcium content (Table 3.5). Vertical infiltration of water is interrupted by the massive lava observed at the spring at which point discharge occurs.

3.4.3 The Nursery Spring

The Nursery Spring (Grid Ref. N36 005 147) has measured discharge between 7.3 and 40.2 litres per minute. It issues from mixed colluvium in confined flow and is situated at an altitude of 270 m on the northern side of French Farm Valley.

Isotope/altitude graphs (Figs. 3.11, 3.12) reveal that most recharge occurs at higher altitudes (see Appendix 4 for reasoning), but a relatively low pH implies significant recharge through the soil layers that mantle much of the area above this spring.

A groundwater flowpath predominantly through surficial cover rather than volcanic material is inferred. This results in a very low iron content (< 0.10 ppm) to the water despite its acidity.

A nursery specialising in growing proteas has been established near Greenmeadows Farm. Irrigation water is

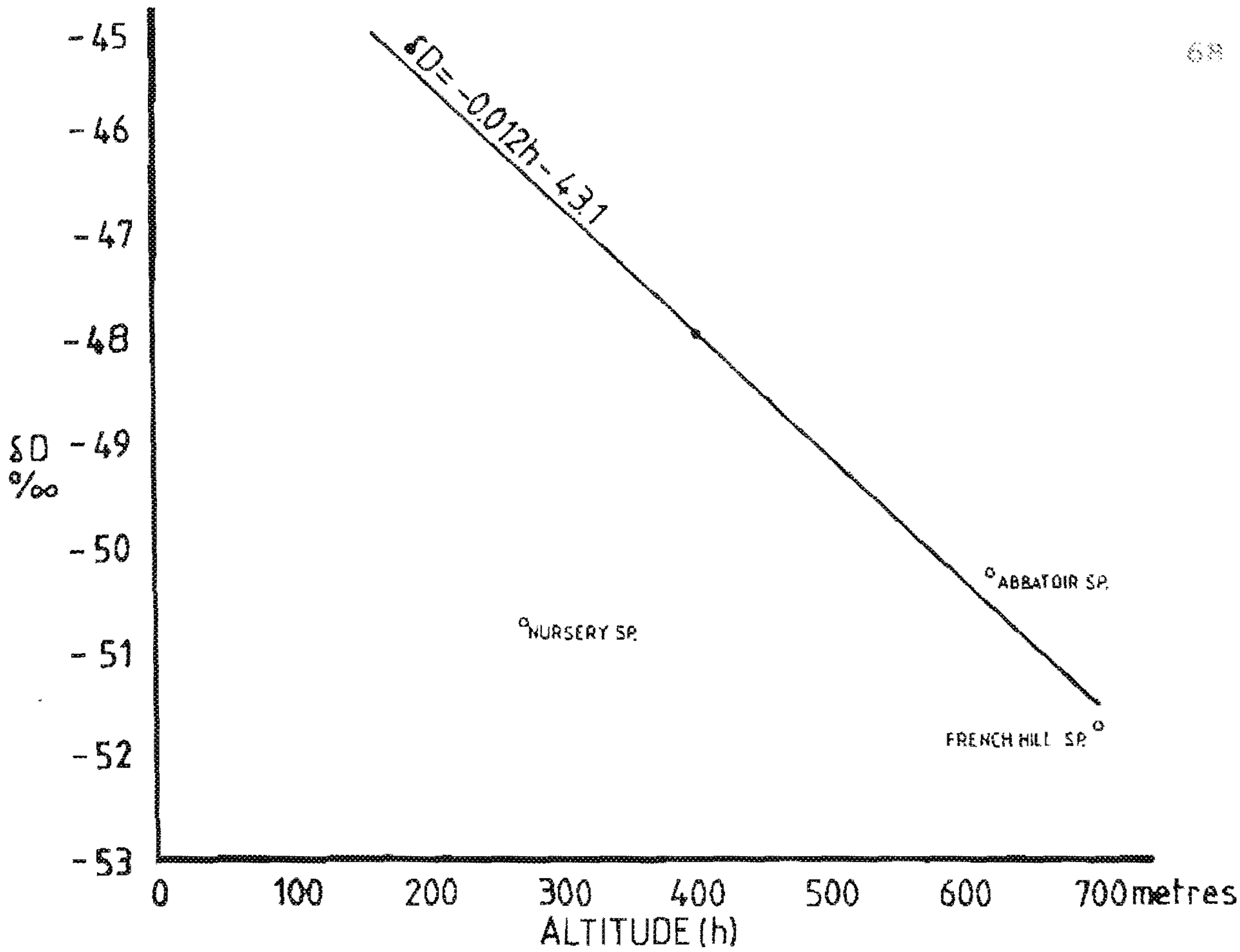


Fig. 3.11 δD values from French Farm springs plotted against spring altitudes. Line is regional (Akaroa County) regression line for isotope / altitude plots.

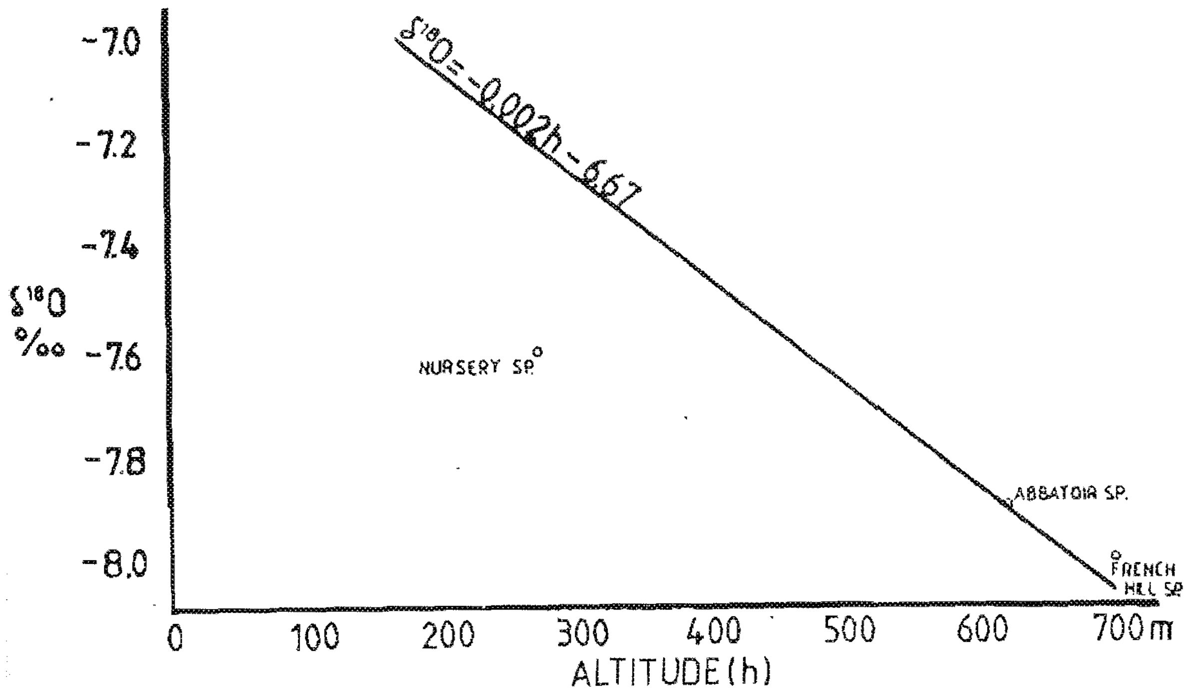


Fig. 3.12 $\delta^{18}O$ values from French Farm springs plotted against spring altitudes. Line is regional (Akaroa County) regression line for isotope / altitude graphs.

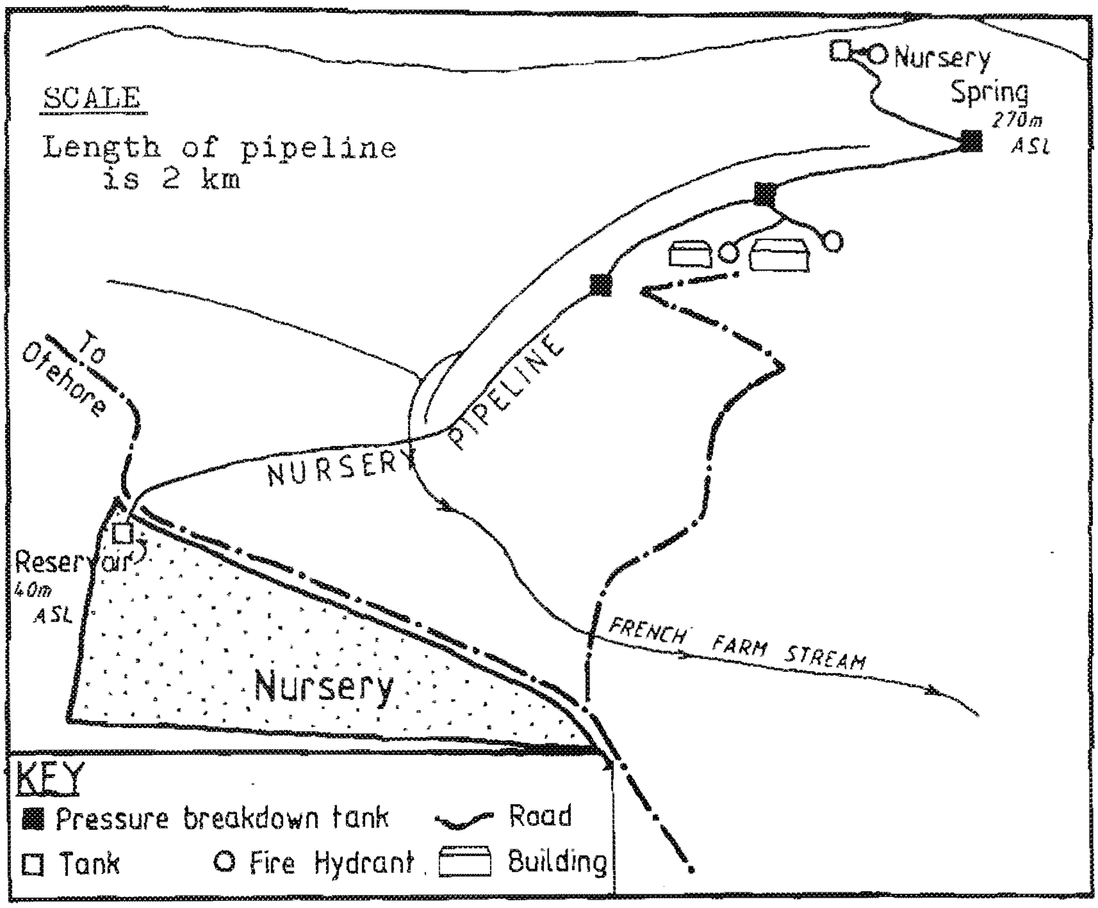


Fig. 3.13 Schematic diagram showing protea nursery irrigation scheme which draws water from the Nursery Spring at an altitude of 270 m on the slopes of French Hill.

drawn from the Nursery Spring via a 2 km length of high density polythene pipe (Fig. 3.13). The 230 m drop en route requires installation of three pressure breakdown tanks at intervals along the pipeline and the water is stored in a wooden reservoir tank above the nursery for use when appropriate.

3.5 HYDROGEOLOGICAL STUDIES ON THE SPRINGS OF FRENCH HILL

Hydrogeological studies relating to the springs of French Hill have been undertaken for two reasons:

1) The need to explain the presence of a number of significant springs that occur within 200 vertical metres of the summit.

2) The requirement of discharge data for two springs in the area because of their potential use for a proposed abattoir nearby.

3.5.1 Setting

The studied area consists of a 40 ha region to the north west of, and including, French Hill (Fig.3.1). Access to this area, 2 km south of the Hilltop Tavern, is via French Peak Road. The landform consists of the upper north west facing slopes of French Hill (815 m) that drop to an extensive flat bench at an altitude of about 620 m (Fig. 3.14). It is drained by a tributary of the Opuahou Stream which flows towards Little River. Where this stream passes under State Highway 75 (Grid Ref. N36 984 166) flow rates between 229 and 3000 litres per minute have been measured (APPENDIX 9). Comparison with spring discharge recorded at the Abattoir Springs shows that a near constant ratio (20% to 26%) is maintained between the spring and stream discharge (Table 3.6) indicating that the stream is mainly spring fed.

Fig. 3.14 Photo showing features of the French Hill study area. The summit of French Hill lies at the top left of the photo. The prominent bench of the area lies at the base of the slopes falling from this summit. "A" is the site of Abattoir Spring #1, and "B" is the spring of Fig. 3.18.

Month	1984 Sep	Oct	Nov	Dec	1985 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Spring Flow	396	209	121	84	64	67	55	51	73	93	785	507
SH 75 Flow	-	996	540	343	289	304	239	229	364	470	3000	-
% Spring/ SH 75	-	21%	22%	24%	22%	22%	23%	22%	20%	20%	26%	-

Table 3.6 Comparison table for spring flow rate (combined flow for Abattoir No. 1 and No. 2 Springs) and the flow of the stream into which they drain (as measured under State Highway 75) during the study period. All flows recorded in litres per minute. The ratio of spring to stream flow is shown as a percentage.

Limited rainfall data is available. Data for the study period, as measured at the nearby Hilltop Tavern, is summarised in Table 3.7. Data from other climate stations leads to the assumption that this rainfall is significantly below average. Daily rainfall for a six week period in June and July, 1985, as measured by a rain gauge installed near the Abattoir springs is summarised in Figure 3.20.

3.5.2 Geology

The geology of French Hill is presented on Figure 3.15 and its accompanying cross section (Fig. 3.16). Much is inferred because of poor volcanic bedrock exposure. Extensive surficial cover, mainly mixed and volcanic colluviums, exists. The volcanic geology consists of variably jointed basic lavas (basalt, hawaiite, and mugearite (Falloon, 1982)) dipping at very low angles (4^o measured) to the north west, with intermittent ash

Month	1984 Sep	Oct	Nov	Dec	1985 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Tot.
Rain-fall (mm)	118	64	67	86	12	75	80	31	135	40	208	133	1047

Table 3.7 Rainfall as recorded at the Hilltop Tavern (Grid Ref. N36 995 176) during the study period (September, 1984 to August, 1985).

layers. Brecciated layers are observed to be present at lower levels, but are poorly developed at higher elevations.

Two prominent flow scarps interrupt the smooth French Hill slopes and show irregular columnar jointing. These have a significant effect on groundwater movement (Fig. 3.16). The lower one has contributed volcanic debris to a large mound that covers part of the prominent bench of the area. This bench is capped by resistant volcanic beds overlain by surficial deposits.

3.5.3 Spring Distribution

Twelve springs have been mapped within this area, most exiting from mixed colluvium. Spring distribution is shown on Figure 3.15. Of special interest are the Abattoir #1 and #2 springs, whose flow rates have been measured over a one year period using V-notch weirs (Appendix 9), because of their potential use by a proposed abattoir.

Springs occur at three discrete levels in the mapped area, these relating to geological factors. The first, and lowest, level relates to the resistant massive lava forming

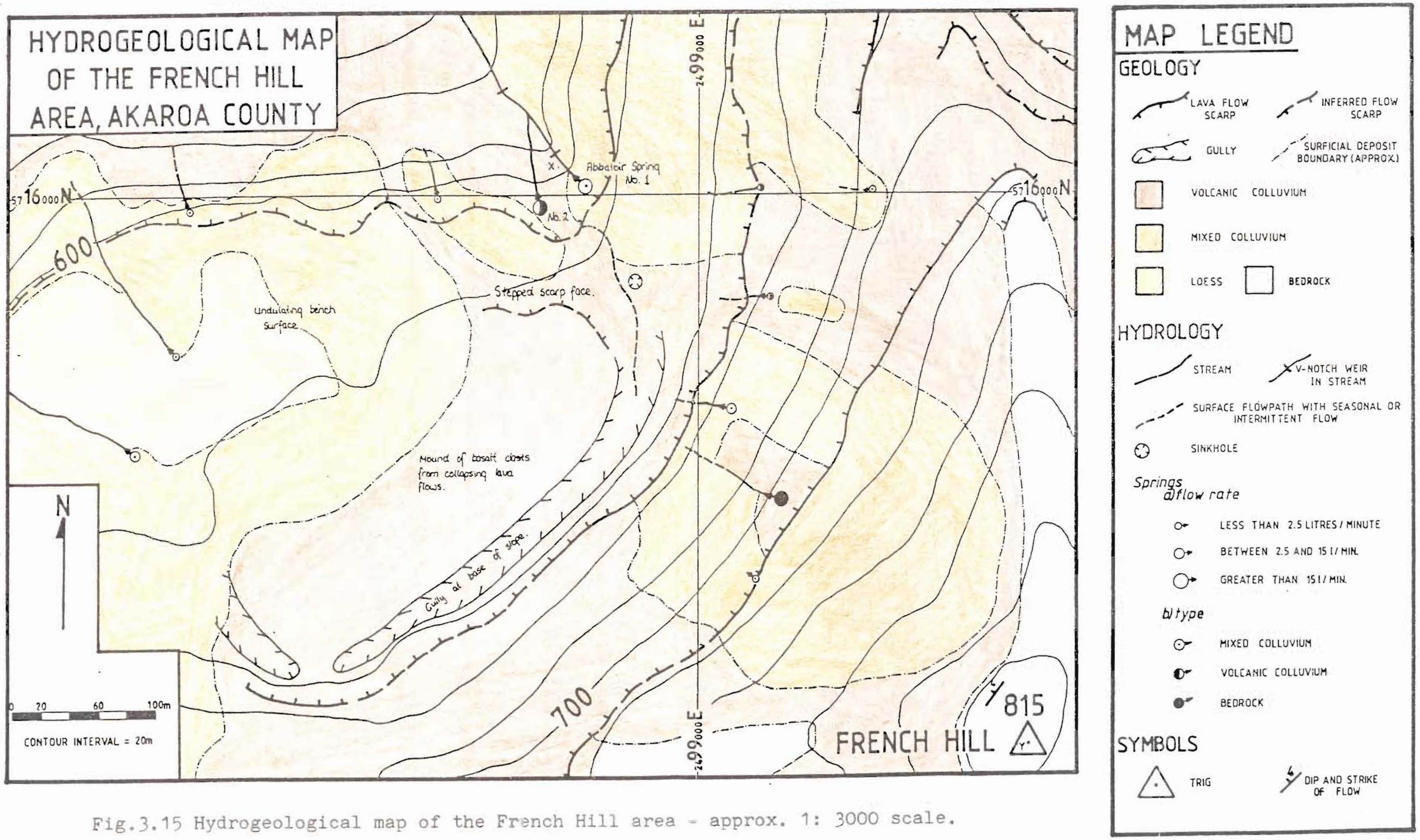


Fig.3.15 Hydrogeological map of the French Hill area - approx. 1: 3000 scale.

Mapped February 1985

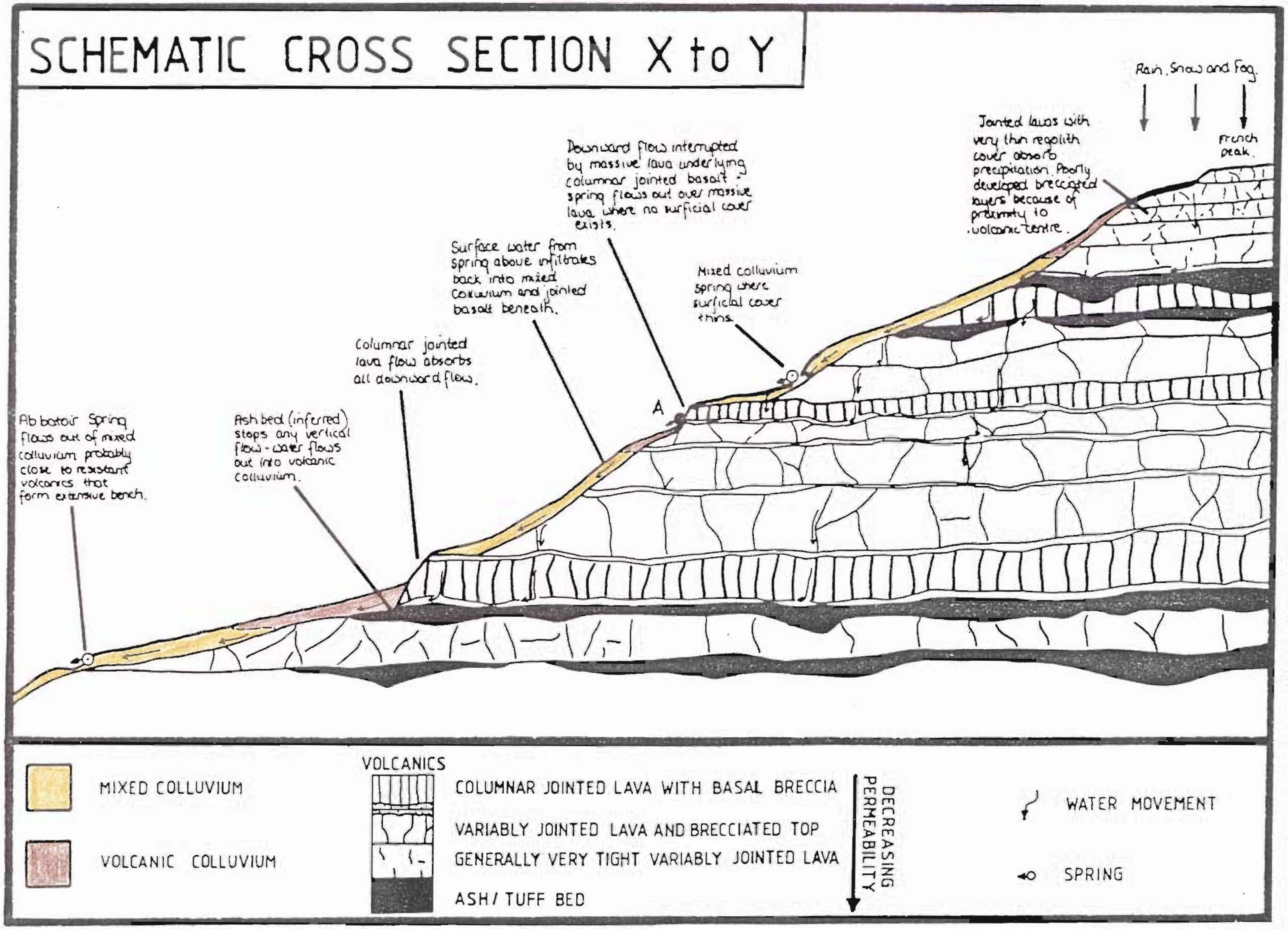


Fig. 3.16 Schematic cross section from X to Y (Fig. 3.15) showing geology (inferred, not to scale) and flowpaths.

the dominant bench of the area. These springs (including the Abattoir springs (Fig. 3.17)) flow from mixed or volcanic colluvium, the waters being perched near to the massive lava. They often relate to a thinning of the surficial cover where the underlying volcanics fall abruptly away at the bench edge (eg. Fig. 2.24).

An intermediate level of springs again emerges from colluvial cover and relates to a tuff layer that is intermittently exposed at this elevation.

The highest springs occur about 100 m below the summit of French Hill, one of these exiting from a columnar jointed phyric basalt over a more massive lava (Fig. 3.18).

3.5.4 Spring Discharge Magnitude and Variability

The springs of the mapped area show high discharge variability, most flowing at less than 2.5 litres per minute for the better part of the year. The Abattoir Springs, however, show measured flows between 18 and 857 litres per minute.

Figure 3.19 shows monthly rainfall totals as observed at the Hilltop Tavern and spring discharge as measured once a month for the Abattoir springs. A seasonal discharge is again apparent with a dramatic peak in the winter period. This is followed by a general decline for the rest of the year due to precipitation and evapotranspiration effects.

Superimposed on the seasonal pattern is the effect of storm events as portrayed in Fig. 3.20. This graph is the result of daily measurement of Abattoir #1 Spring discharge and adjacent rainfall over a six week period. Significant rainfall is followed by an almost immediate (within 24 hours) upturn in spring discharge. A subsequent peak in flow occurs between two and three days after storm cessation followed by a decline until the next storm occurs. A model that explains this behaviour is presented in Section 5.3.1c.

Fig. 3.17 Abattoir Spring emerging from mixed colluvium. At this stage the spring is flowing at about 25 litres per minute (February, 1986). The red colouring is rhodamine wt dye (APPENDIX 6).

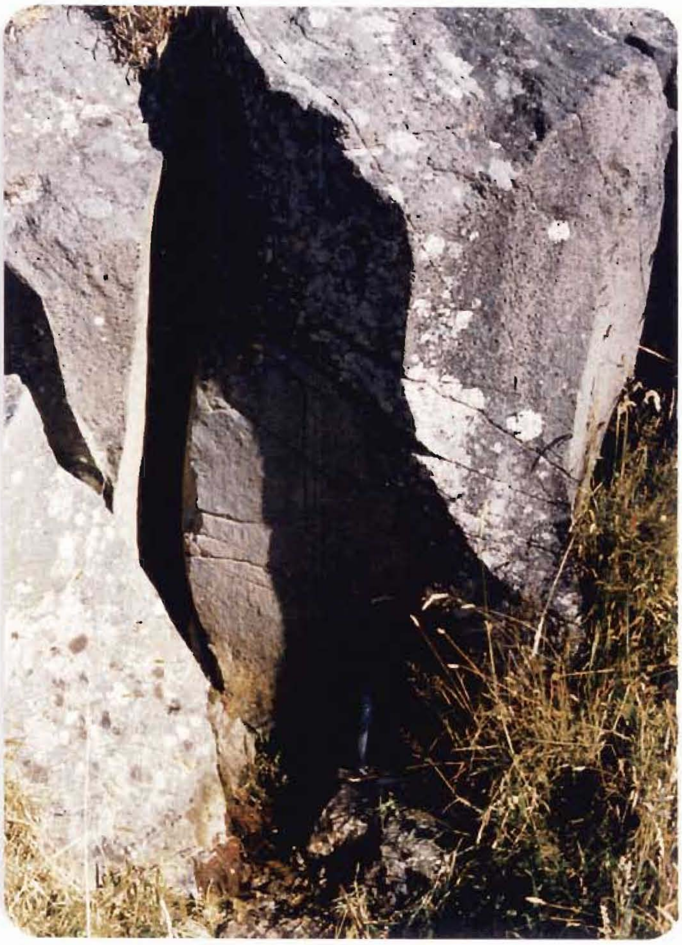


Fig. 3.18 Picture of the highest spring on French Hill (Fig. 3.14) (at base of photo beside hammer). This spring emerges from columnar jointed basalt over a more massive basalt.

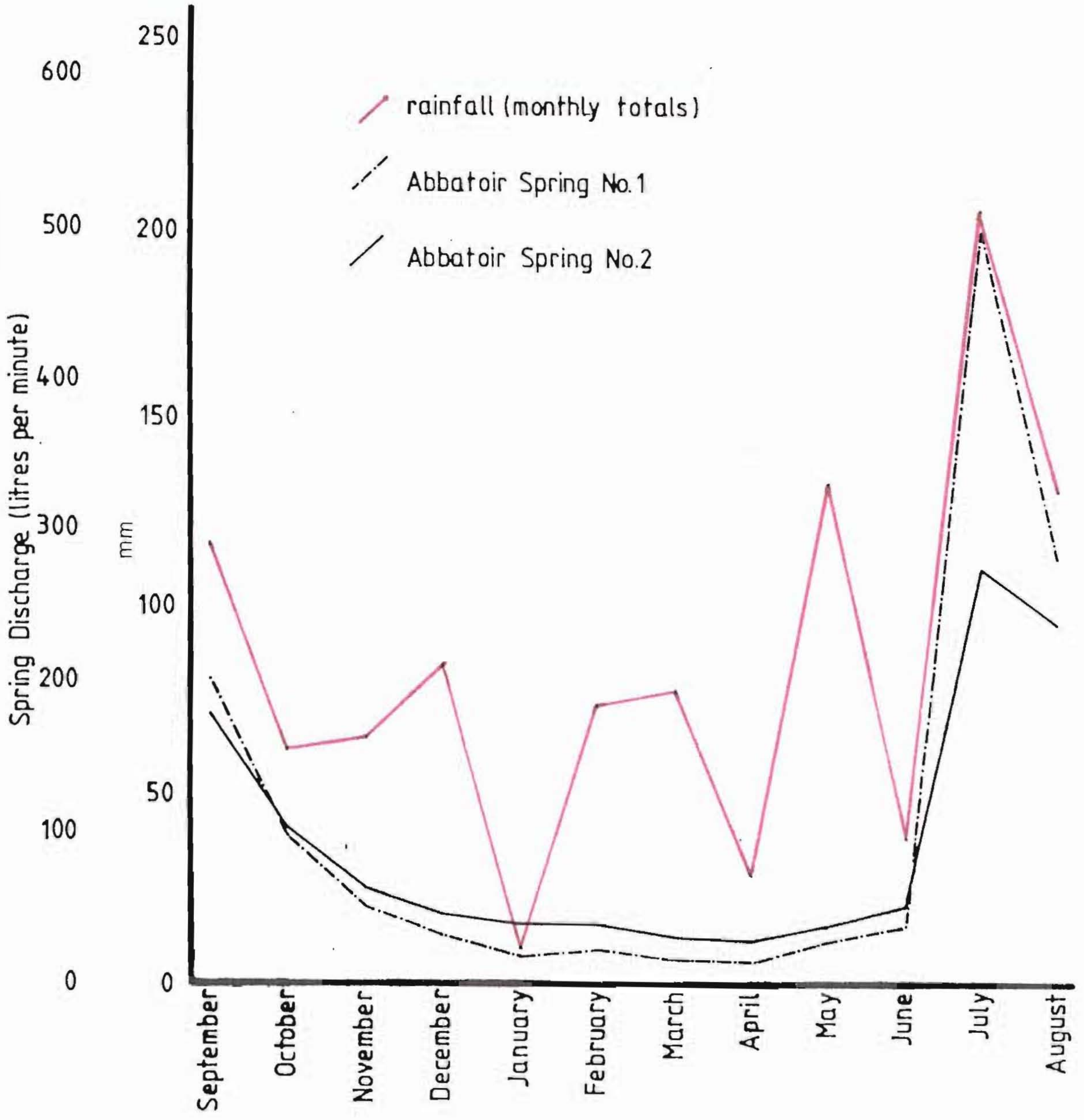


Fig. 3.19 Plot of spring discharge for Abattoir No. 1 and No. 2 Springs (APPENDIX 9)and corresponding rainfall data as measured at the Hilltop Tavern (N36 995 176) between September, 1984 and August,1985.

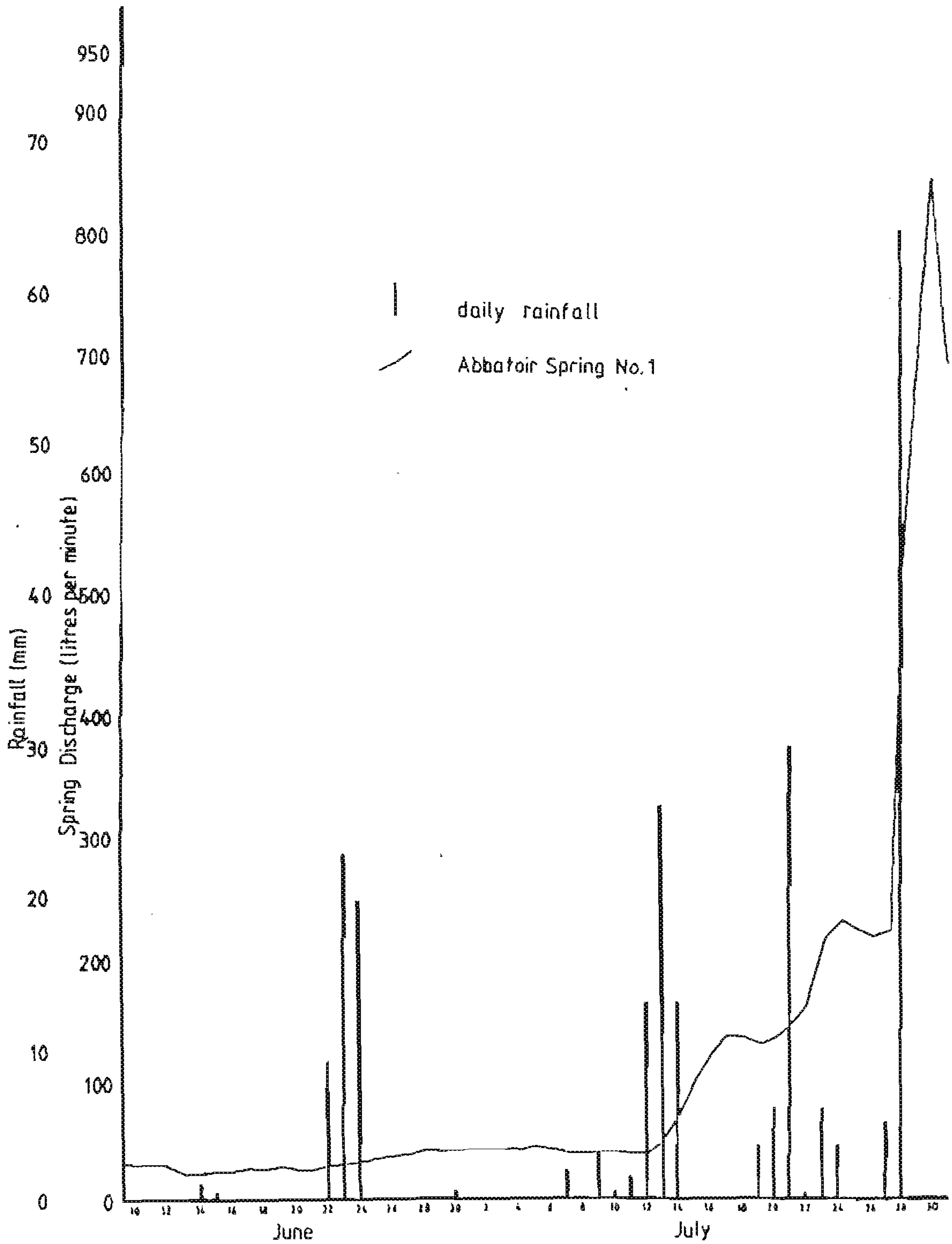


Fig. 3.20 Daily rainfall and spring discharge as measured over a period between 9 June and 31 July at the Abattoir #1 Spring.

3.5.5 Spring Recharge

This area is of interest with respect to recharge source because of the existence of springs so close to the summit ridges. High flow (> 15 litres per minute) springs encircle French Hill at a similar altitude (Fig. 3.2). Isotope values (Table 3.4) for Abattoir Spring No. 1 do, however, support a direct precipitation - infiltration model, these results plotting directly on the meteoric water line (Fig. 3.9).

The presence of springs close to the summit of French Hill can be explained by two factors: precipitation rate, and geologic influence. French Hill has a mean annual precipitation of approximately 1400mm (Fig. 1.3), this occurring as rain or snow melt. This is complemented by geology that is conducive to infiltration. Some of the exposed lavas show open jointing (up to 3cm) which is expected to absorb a lot of the rain or snow melt that occurs on it. The low dip of these lavas means that a higher number of vertical joints per unit area are exposed than would be if the lavas were steeply dipping.

The predominance of mixed and volcanic colluvium in the French Hill area means that permeabilities of between 10^{-5} and 10^{-7} m/s (Table 2.2) are expected, with infiltration rates being of a similar magnitude.

Fig. 3.21 summarises possible recharge areas for the various springs of the study area. Many of the springs are reabsorbed soon after emergence and these may feed springs at a lower level, eg. the two Abattoir springs may be fed by level 1 & 2 springs as well as infiltration waters from areas 1, 2, & 3. This is supported by the existence of an apparently dry gully and sink hole at the base of the slope above the Abattoir springs (Fig. 3.15). These may be surface expressions of subsurface water flow towards these springs.

This nearby recharge area for the Abattoir Spring #1

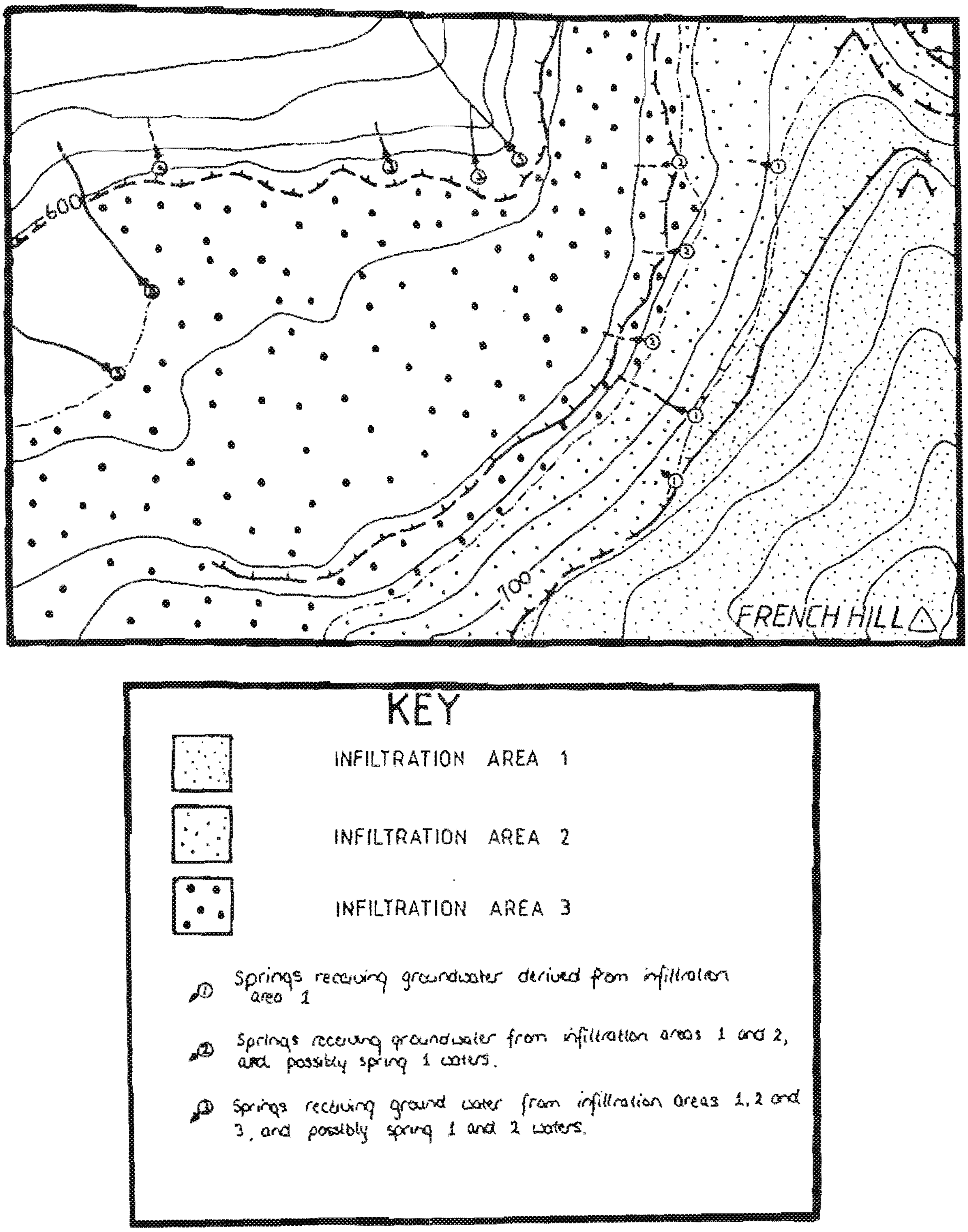


Fig. 3.21 Model showing possible recharge areas for the springs of the French Hill study area. Contour interval is 20 m. Symbols are the same as for Figure 3.15.

is further confirmed by the proximity of isotope values to the regional regression lines of the isotope/altitude graphs. A high iron content indicates that a significant flow path exists through the lavas of the area.

Rhodamine Wt dye tracing (Appendix 6) of infiltration water has been attempted to further support this model. This was generally unsuccessful because of absorption of dye by the silt and clay fractions of surficial deposits. Dye inserted directly into the columnar jointed lava above the top high flow spring (Fig. 3.18) did emerge from this spring however, being consistent with downward percolation of precipitation waters.

3.6 SUMMARY OF SPRING OBSERVATIONS FROM FRENCH FARM

1) Spring distribution is geologically controlled. Springs emerge from various lithologies, these being, in order of decreasing frequency as spring sources: mixed colluvium, volcanic colluvium, loess colluvium, and bedrock.

2) Surficial deposits may confine groundwater that has derived from bedrock material.

3) Intrusive bodies may form barriers to groundwater movement that can result in spring occurrence.

4) Springs are most common at higher altitudes (above 250 m) where most recharge appears to occur.

5) Isotope data is consistent with a precipitation - infiltration recharge model.

6) The majority of springs flow at less than 2.5 litres per minute. Only 5% of the mapped springs flow at greater than 15 litres per minute.

7) Spring discharge shows seasonal variability with a peak in July followed by a gradual decline to a

minimum in autumn. This variability is related to recharge fluctuations that appear dependent on precipitation and evaportranspiration variations.

8) Water quality testing of three French Farm Springs indicates water suitable for drinking water supply.

CHAPTER 4

HYDROGEOLOGICAL STUDIES ON SPRINGS IN PIGEON BAY VALLEY

4.1 INTRODUCTION

Hydrogeological studies relating to the springs of Pigeon Bay Valley have been undertaken for two reasons:

1) It lies on the outer flanks of Akaroa Volcano.

2) A water supply problem has existed in this area.

Because of the general down - valley dip of the lava flows of Pigeon Bay Valley higher discharge magnitudes and/or a greater concentration of springs than in French Farm were theorised. To determine the hydrogeological and recharge models relating to the springs of Akaroa County it was necessary to test this theory, using tools including hydrogeological mapping and discharge monitoring, in Pigeon Bay Valley.

At commencement of the study the Akaroa County Council were considering the use of the Cemetery Spring (Grid Ref. N36 027 227), or other suitable springs, as supplementary water supply sources for the main settlement of Pigeon Bay. Discharge data was therefore desirable for supply management considerations. Further consideration by the Council has resulted in the proposed drawing of water directly from Pigeon Bay Stream however.

4.2 SETTING

Pigeon Bay lies on the northern rim of Banks Peninsula. Pigeon Bay Valley trends for 6 km in a southerly direction back from the sea running through alluvial flats before climbing steeply to the ridge at its head at a height of approximately 400 m. The Summit Road runs along this

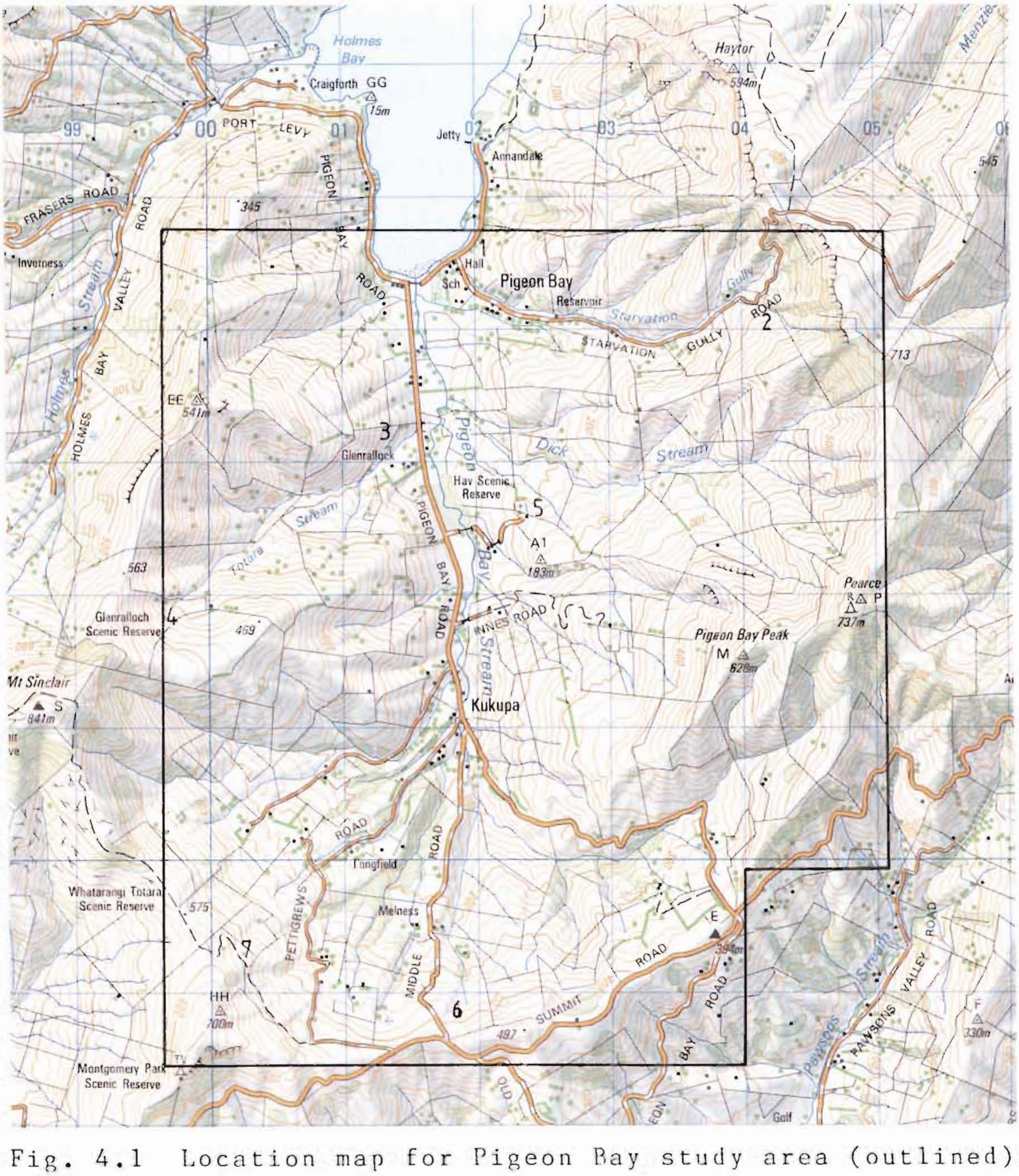


Fig. 4.1 Location map for Pigeon Bay study area (outlined). Map is a section of NZMS 260, N36, 1:50,000 Map.

Numbers refer to studied springs, ie.

1 Bull Paddock Spring
2 Starvation Gully Springs
3 Bottom Glen Spring
4 Top Glen Spring
5 Cemetery Spring
6 Top Pigeon Bay Spring
7 Old Summit Road Spring

ridge. Road access is from Port Levy or from Akaroa (34 km) or the Hilltop via the Summit Road. The studied area (Figs. 4.1, 4.2) centres on this valley and includes its two other bounding ridges on the east and west. These resistant volcanic ridges rise to peaks at Trig HH (700 m) in the west and Peacee (737 m) and Pigeon Bay Peak (628 m) in the east.

Two streams enter Pigeon Bay at its head. Pigeon Bay Stream drains the main valley, with measured flows between 41 litres per second and 396 litres per second (Appendix 10). Many tributaries, including Dick and Totara streams, feed into this main stream. Starvation Gully Stream issues from the steep gully running in a easterly direction from the base of the main valley and has measured flows between 30 and 236 litres per second (Appendix 10). The streams of the area appear to be mainly spring fed, most continuing to flow during dry periods.

No rainfall data is available for Pigeon Bay but Figure 1.3 implies an average annual rainfall of between 1000 and 1200 mm for this area. Southwesterly derived rain makes a significant contribution near the Summit Road but decreases in importance further down the valley due to a rain shadow effect. As a result the response of spring discharge to southwesterly storms is generally more pronounced in the Summit Road region than further down valley. The northeasterly is an important rain - bearing wind in Pigeon Bay. In summer this is mainly a sea breeze carrying little rain, but when part of a cyclonic system in winter often brings persistent rain.

Land use is confined mainly to sheep and cattle fattening though limited dairying or horticulture (yam growing) does exist. This is a popular recreational area as evidenced by a number of baches, a motor camp, and the Pigeon Bay Boat Club. The farms and temporary residences are serviced by a store and school at the base of the valley.

Farms in the upper valley draw water from nearby

<u>Fig.</u> <u>4.2</u> Panorama showing Pigeon Bay study area. View is from the Summit Road (N36 015 187) towards Pigeon Bay. Note bench in foreground with associated swampy patches relating to seeps. Benches are well developed on both valley sides and springs are usually associated with them. Volcanic colluvium is rare on the eastern (right in photo) valley side, but common on the western side due to a slight westerly dip of the lavas.

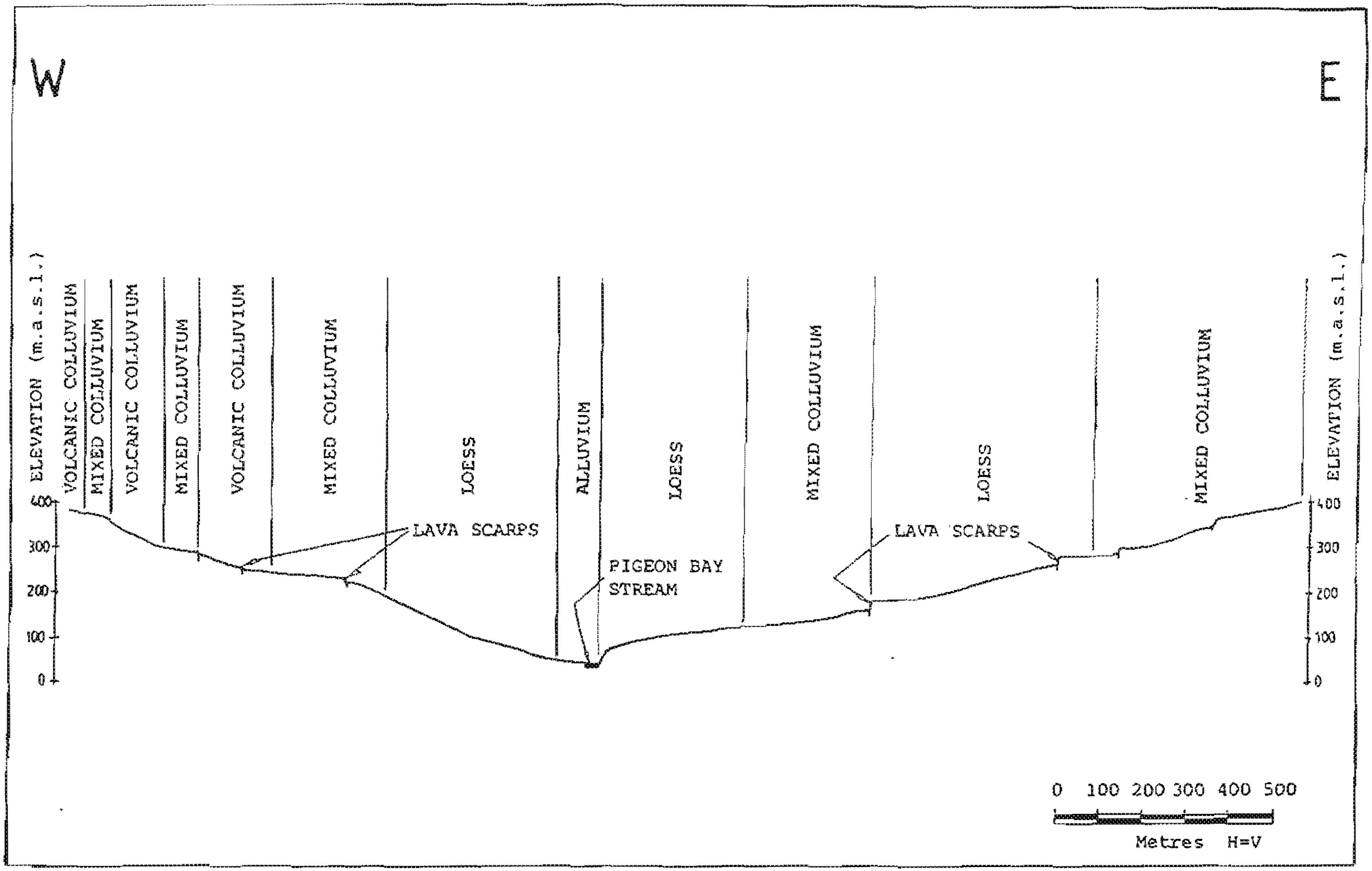


Fig. 4.4 Schematic cross section of Pigeon Bay Valley showing valley asymmetry and distribution of colluvial materials (NB. lava scarps are not to scale).

creeks or springs, while houses and services in the lower valley are presently served by a reservoir deriving water from Starvation Gully Stream and supplemented by the Bull Paddock Spring (Fig. 4.1). The lower valley supplies have, however, proved inadequate and the new replacement supply is proposed by the Akaroa County Council. Water will be drawn from Pigeon Bay Stream near the valley base and be pumped through a sunken filter to a tank from which most consumers will be gravity - fed.

4.3 GEOLOGY AND GEOMORPHOLOGY

Figure 4.3 (in map pocket) presents the geology and hydrology relevant to the springs of Pigeon Bay Valley. The lavas of Pigeon Bay appear to be of the same basic composition as French Farm, ie. basalts, hawaiite, and mugearite. Basalts are dominant and flows usually dip at low angles (6^{o} measured) to the north north west. The lavas are commonly exposed in lengthwise section, due to their down - valley dip, and flows generally thin towards the bay. The north - south trend of the main valley results in an asymmetry with the western slopes rising more abruptly due to truncated lavas (Fig. 4.3). The eastern side has smoother dip - sloping walls, but both sides show well developed bench systems picking out lava flow dips (Figs. 4.2, 4.4). These are frequently capped by tuff or scoria beds, or massive lavas or lava - derived products, such as massive weathered breccias.

This asymmetry affects surficial composition, volcanic colluvium being much more prevalent on the western valley side due to joint - controlled wedge failure of lava blocks (average size 100 - 450 mm) onto the slopes below. Mixed colluvium predominates on the eastern dip slopes. This may also be controlled to some extent by the attitude these slopes provided to the loess - bearing north west winds. Volcanic exposure is generally better in the west, but surficial deposits again restrict mapping of the underlying beds.

Pyroclastic deposits are subordinate to lavas and include red tuff beds, some crystal tuffs, and thick (up to 20 m) bedded scorias. Good examples of scoria beds are seen in Totara Stream (Grid Ref. N36 003 224) and near the summit of Pigeon Bay Peak. Pyroclastic beds are often significant perching layers, and fragments of red ash are observed in many springs emerging from colluvium material as well as bedrock springs.

Intrusives are very poorly exposed but are assumed to be present as trachyte or basalt components of the Akaroa Dyke Swarm. Previous workers have observed dolerite dykes at the head of Pigeon Bay Valley.

4.4 THE SPRINGS OF PIGEON BAY VALLEY

4.4.1 General

Distribution

Over 470 springs have been mapped in Pigeon Bay Valley between April and July, 1985 (Fig. 4.3). Springs are concentrated in the upper slopes close to the major ridgetops of the area as occurs at French Farm. The study area has again been divided into two similarly sized areas to statistically compare spring occurrence on upper and lower slopes, the division being made at the 300 m contour. Approximately half of the mapped area and two - thirds of the springs lie above this altitude. About half of the total number of springs lie on either side of Pigeon Bay Stream indicating that the variation in lava dip from one side to the other is not enough to significantly influence spring size or distribution.

The relative significance of the various spring types is summarised in Table 4.1. Most springs (66%) emerge from mixed colluvium, followed by volcanic colluvium (19%). Because of the colluvium distribution difference from one valley side to the other nearly all volcanic colluvium derived springs lie on the western side of the valley while

Type	Loess	Mixed colluvium	Volcanic colluvium	Bedrock	Alluvium
Number of Springs	38	314	90	29	3
% of Total	8%	66%	19%	6%	1%

Table 4.1 Relative abundance of the various spring types as mapped in Pigeon Bay Valley.

the majority of mixed colluvium springs are on the more gently dip - sloping eastern valley side. A small number of springs emerging from loess (8%) and bedrock (6%) occur, and only a very few springs exit from alluvium. Sub - equal numbers of loess springs exist on both valley sides while the low number of directly bedrock derived springs again reflects extensive colluvial cover.

Below the 300 m contour springs emerging from mixed colluvium still dominate but loess springs have become more important. Nearly all loess springs lie below the 300 m level. All alluvium springs are below this level, but only about a third of all springs issuing from mixed and volcanic colluvium and bedrock are in this region.

The importance of relatively impermeable volcanic lithologies in influencing spring distribution is evident in Pigeon Bay Valley. These often act as perching layers, and include in apparent order of decreasing importance: tuff (and ash), tightly or poorly jointed lava, highly weathered unbrecciated lava, weathered and/or compacted brecciated layers, welded or weathered scoria beds, and weathered vesicular lava. Springs emerging from colluvial and bedrock materials often show one of these perching layers at their exit and these have been recorded on the hydrogeological map (Fig. 4.2).

Fig. 4.5 View into Totara Stream from Starvation Gully showing springs related to benches (arrowed). Many other springs are visible as dark green patches on the brown hillsides. The lines of bush at the valley head relate to flow scarps and show the low dip of the lavas.

Springs are commonly related to geomorphic benches which are frequently capped by one or more of the perching lithologies (Fig. 4.2). Lines of springs are often observed on hillsides at levels coinciding with these bench tops confirming the influence of the perching layers on spring distribution even where benches are not present. This is clearly observed at the head of Totara Stream (Fig. 4.5). In some cases this simple pattern may be masked due to the confining effect of surficial cover.

Spring Discharge Magnitude and Variability

Table 4.2 summarises the relative numbers of springs occurring within the selected flow rate ranges (Appendix 3) when they were mapped during the autumn period (1985). Most

Flow type	Low	Medium	High
Discharge range (litres/minute)	< 2.5 l/min.	2.5 - 15 l/min.	> 15 l/min.
Number of springs	404	62	9
% of Total	85%	13%	2%

Table 4.2 Relative abundance of springs occurring in the various discharge ranges (APPENDIX 3) in Pigeon Bay Valley when mapped in the autumn of 1985.

of the springs (85%) flow at less than 2.5 litres per minute, 13% are between 2.5 and 15 l/min., and only 2% are greater than 15 l/min. A similar discharge distribution occurs above and below the 300 m contour, and similar numbers of low and medium sized springs occur on either side of the valley. Spring monitoring indicates that autumn is the period when lowest discharge magnitudes were occurring (Fig. 4.) and it is assumed that some of the mapped springs will enter a higher discharge category in the winter period.

Spring	Grid Reference NZMS 260	Altitude m	Max Flow Rate litres/min	Min Flow Rate litres/min	Type	Isotope Reading $\delta^{18}O$	δD
Bull Paddock Spring	N36 020 246	25m	-	-	Mixed Colluvium	-7.1	-47.0
Starvation Gully Springs							
1	N36 042 242	400m	5.6	0.1	Mixed Colluvium	-7.6	-47.9
2	N36 042 242	400m	14.0	1.6	Mixed Colluvium	-	-
3	N36 042 242	400m	7.3	2.0	Mixed Colluvium	-	-
Bottom Glen Spring	N36 013 233	90m	22.8	8.5	Bedrock	-7.8	-52.4
Top Glen Spring	N36 997 218	460m	21.6	4.8	Mixed Colluvium	-8.0	-50.2
Cemetery Spring	N36 027 227	120m	21.0	6.8	Loess	-	-
Top Pigeon Bay Spring	N36 018 189	360m	18.8	0.7	Mixed Colluvium	-7.5	-47.6
Old Summit Rd Spring	N36 003 193	490m	10.7	Dry	Mixed Colluvium	-7.7	-49.7

Table 4.3 Summary table of data from nine Pigeon Bay Valley Springs.

Nine Pigeon Bay springs have been studied in some detail. Their position and some particulars are presented in Table 4.3. Discharge for eight of these springs was monitored over a one year period and the results are plotted on Fig. 4.6. The observed seasonal trend shows a decline in the period from spring to autumn, followed by a short - lived increase following rainfall in July. Springs close to their catchment source, usually the high springs, such as Top Pigeon Bay Spring, tend to be more erratic than the lower springs, eg. the Old Summit Road Spring ceased flow between February and June, 1985.

Recharge

Oxygen-18 and deuterium testing of water from six Pigeon Bay springs has been undertaken (Table 4.3). The isotopic compositions of these waters plot close to the Meteoric Water Line derived for New Zealand rainwater (Fig. 4.7, Appendix 4) indicating that a precipitation - infiltration recharge model is appropriate in Pigeon Bay Valley as it is in French Farm.

Water Quality

Chemical analysis results for five Pigeon Bay springs are summarised in Table 4.4 (see Appendix 5 for full analyses). The following observations can be made with respect to potable water quality:

1) All springs tested are considered suitable as drinking water sources.

2) Slight acidity (especially of the Starvation Gully #1 and Top Glen springs) may lead to corrosion of metal water supply fittings. The Bottom Glen Spring (pH = 7.4) is the only spring that is not outside the desirable range for drinking water (New Zealand Standards). Aeration does bring all samples into an acceptable range however.

3) The turbidity of the Pigeon Bay Hilltop Spring

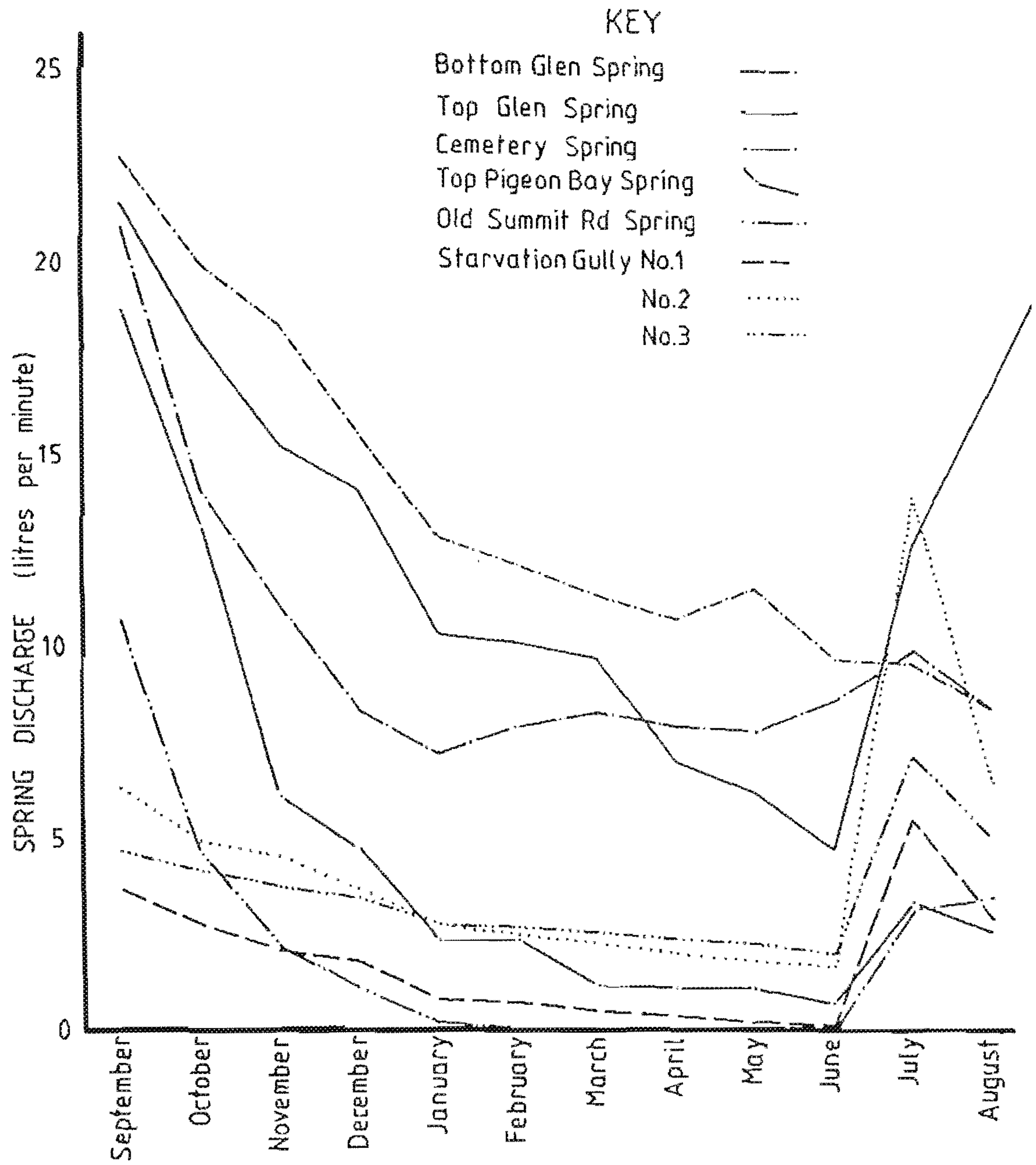


Fig. 4.6 Spring discharge (APPENDIX 9) for eight Pigeon Bay springs as measured between September, 1984 and August, 1985.

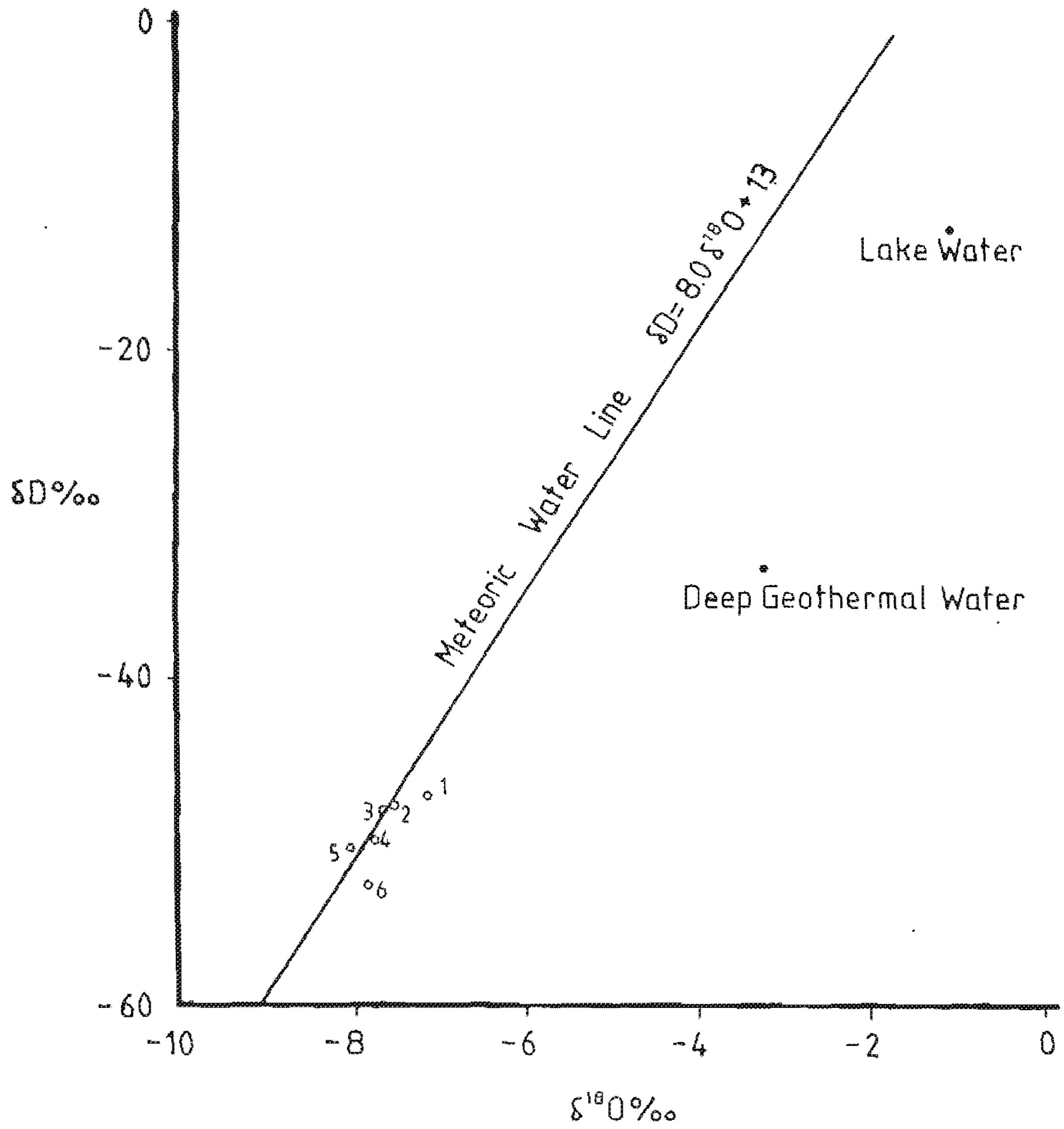


Fig. 4.7 Plot of deuterium and oxygen-18 contents for water samples taken at six Pigeon Bay Valley springs. Note the proximity of the samples to the N.Z. Meteoric Water Line. Lake water and deep geothermal samples are from Stewart and Taylor (1981) and are plotted for contrast. Sample numbers are:

1 Bull Paddock Spring
2 Top Pigeon Bay Spring
3 Starvation Gully Spring
4 Old Summit Road Spring
5 Top Glen Spring
6 Bottom Glen Spring

Spring	Sample Number	Grid Reference NZMS 260	pH	Aerated pH	Turbidity (NTU units)	Nitrate Nitrogen g/m^3	Chloride g/m^3	Sodium g/m^3	Magnesium g/m^3	Calcium g/m^3	Iron g/m^3	Hardness (as $CaCO_3$) g/m^3
Bull Paddock Spring	KB339	N36 020 246	7.3 #	8.3	0.4	1.8	61	72	18.0	30.0	0.08	149*
Starvation Gully No 1	KB338	N36 042 242	6.0 ##	7.6	0.5	3.4	24	19	1.9	6.4	0.16*	24
Bottom Glen Spring	KB341	N36 013 233	7.4	8.3	0.5	4.9	43	49	8.8	18.0	0.10	81*
Top Glen Spring	KB340	N36 997 218	6.8 ##	7.7	0.2	0.6	20	13	1.5	5.4	0.10	20
Top Pigeon Bay Spring	KB316	N36 018 189	7.0 #	7.6	1.5*	1.8	20	16	1.6	5.9	0.10	21

This sample does not comply with the following N.Z. standard requirements:

Outside desirable range
Outside maximum range
* Exceeds lower guideline limit
** Exceeds upper guideline limit

Table 4.4 Summary table showing results of chemical analyses of five Pigeon Bay Valley springs (APPENDIX 5 shows full analyses).

(1.5 NTU) exceeds lower guideline limits of the New Zealand Standards for Drinking Water (APPENDIX 5) although no discolouration is observed.

4) Nitrate nitrogen contents are well within the guideline value for potable water (10 g/m^3) with the Bottom Glen Spring possessing the highest value (4.9 g/m^3).

5) The sodium and chloride contents for the Bull Paddock and Bottom Glen springs are unusually high for this area though well below lower guideline values (100 g/m^3) and taste thresholds (between 200 and 300 g/m^3) for drinking water.

6) The Starvation Gully #1 Spring exhibits excessive iron content though this does not exclude it from human consumption.

7) The springs of Pigeon Bay yield generally soft waters. The Bottom Glen Spring is classified as moderately soft and the Bull Paddock Spring is slightly hard however.

Interpretations with respect to the groundwater history of the five Pigeon Bay springs for which chemical, isotope, and geological data is available can be made (see Appendices 4 and 5 for reasoning). A direct precipitation - infiltration recharge model is assumed in making these interpretations. Discussion of these interpretations, together with other relevant details, is presented in the following five sections.

4.4.2 <u>Starvation Gully Spring #1</u>

The Starvation Gully #1 Spring flows at between 0.1 and 5.6 litres per minute (Appendix 9) from out of mixed colluvium. It lies at an altitude of 400 m (Fig. 4.1) and is piped away for domestic use further down valley.

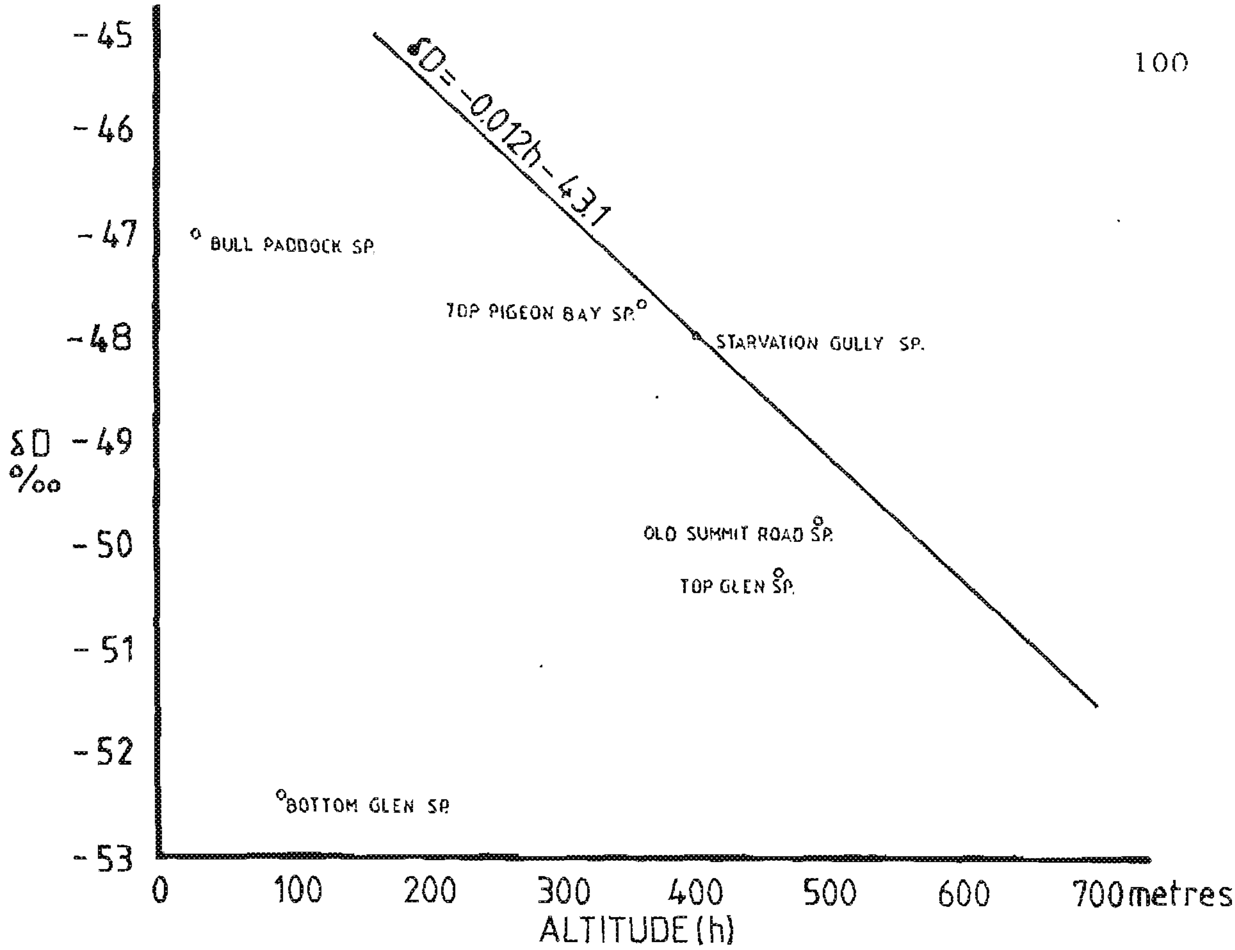


Fig. 4.8 δD values of Pigeon Bay springs plotted against spring altitudes. Line is regional (Akaroa County) regression line for isotope / altitude plots.

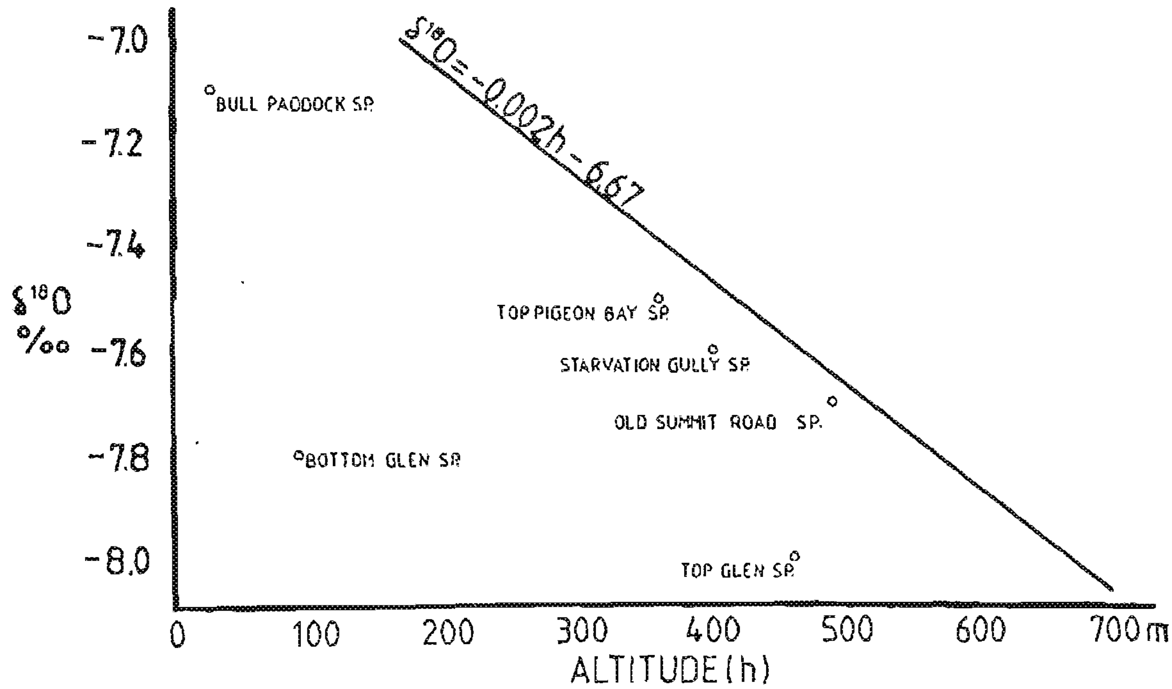


Fig. 4.9 $\delta^{18}O$ values of Pigeon Bay springs plotted against spring altitudes. Line is regional (Akaroa County) regression line for ^{18}O / altitude plots.

A nearby recharge area is suggested by the proximity of deuterium and oxygen-18 values to "best fit" lines on isotope/altitude graphs (Figs. 4.8,4.9). Recharge involves significant percolation through soil resulting in unusually high nitrate contents and low pH. It is inferred that significant recharge may occur on the adjacent mixed colluvium pasture lying above and to the south east of this spring.

A high iron content, in combination with moderately low sodium/ magnesium/calcium (Na/Mg/Ca) values, is consistent with a short groundwater flow path through volcanics.

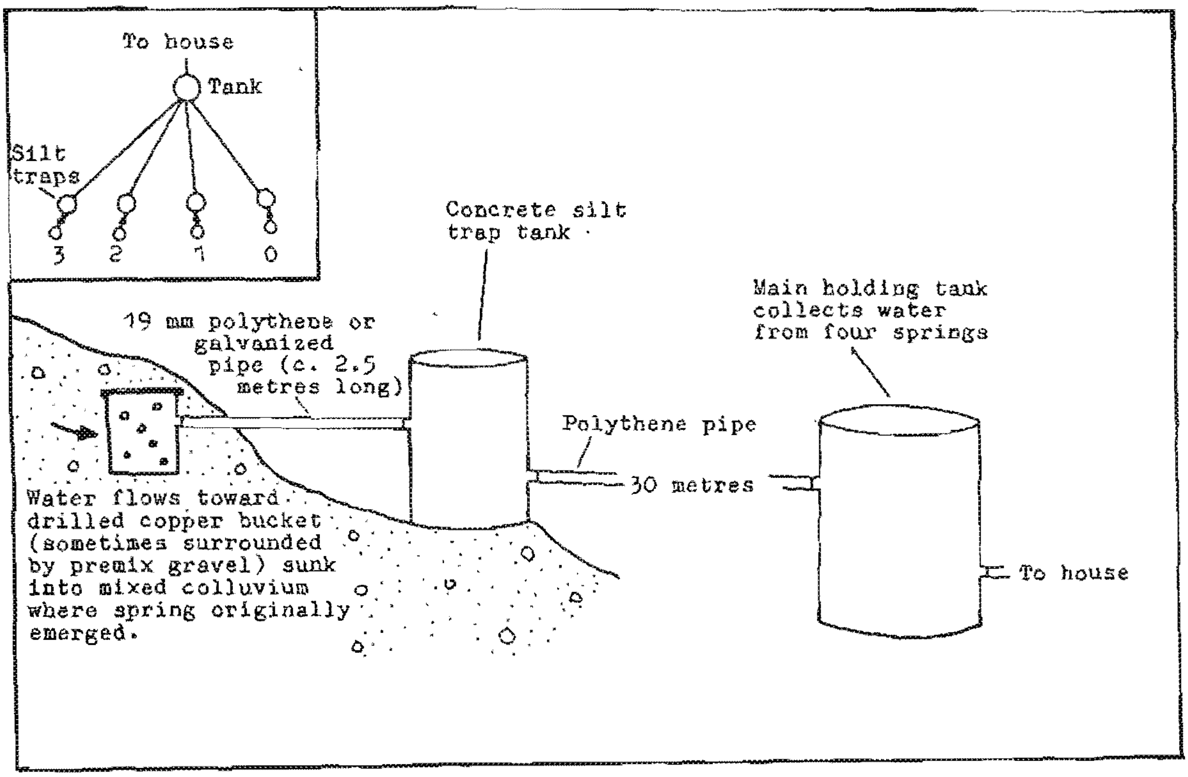


Fig. 4.10 Starvation Gully farmhouse water supply as it appears at the water intake. The inset shows the intake in plan view, the numbers representing the four "Starvation Gully Springs" (Fig. 4.3, in map pocket).

A water supply that is similar to many used throughout Akaroa County for stock water and house supplies draws water from the Starvation Gully #1 Spring and three adjacent springs. This water is piped for 2 km to be used in a farmhouse water supply and garden irrigation.

Each spring is tapped by a single drilled copper bucket sunk into mixed colluvium at the spring exit (Fig. 4.10). Polythene pipe carries water an average of 2.5 m to small concrete silt traps from which the water is piped a further 30 m to where all four sources feed into a holding tank. Water is piped from this tank down - valley to the Goodwin's farmhouse.

4.4.3 <u>Bull Paddock Spring</u>

The Bull Paddock Spring is a medium flow spring lying at an altitude of 25 m near to the foreshore of Pigeon Bay at the base of Starvation Gully (Fig. 4.1) . It flows from mixed colluvium over tightly jointed lava. This spring presently supplements the Pigeon Bay water supply.

The main recharge area is at a significantly higher altitude than the spring. Oxygen-18 and deuterium values indicate an average altitude of recharge between 200 m and 300 m above the spring (Figs.4.8, 4.9). Most significant water contribution is probably from higher altitudes (rocky ground) resulting in only a moderate nitrate content and near neutral pH. Some recharge occurs at lower levels however, as shown by unusually high sodium and chloride contents resulting from solution of sea spray by infiltrating rainwater. A long volcanic flow path results in high Na/Mg/Ca values.

The long flow path from the main recharge area has resulted in a slight deviation from the Meteoric Water Line (Fig. 4.7). This deviation may be due to several factors (Stewart and Taylor, 1981) including:

1) Chemical interaction of water with the aquifer materials leading to isotope exchange

2) Isotope separation during water transport (mainly diffusion).

4.4.4 Top Glen Spring

The Top Glen Spring is situated at the head of Totara Stream at a height of 460 m (Fig. 4.1). It supplies stockwater troughs and seasonally variable measured flows range between 4.8 and 21.6 litres per minute (Appendix 9). Springwater is perched above deeply weathered massive basalt and flows out of mixed colluvium.

Isotope concentrations indicate a short average flowpath from the recharge area. A relatively low pH indicates significant percolation through soil layers combined with a short volcanic flowpath. The short volcanic component is confirmed by a low proportion of Na/Mg/Ca and very low iron content.

4.4.5 Bottom Glen Spring

Situated at the base of Totara Stream, at an altitude of 90 m (Fig. 4.1), the Bottom Glen Spring flows from a thin brecciated lava over- and underlain by tuff. Measured discharge varies between 8.5 and 22.8 litres per minute.

A large water input from a recharge source, probably near the summit region to the west of the spring, is implied by a strong deviation of this spring from the "best fit" line on the isotope/altitude graphs (Figs. 4.8, 4.9). Some recharge occurring at lower altitudes is implied by unusually high sodium and chloride contents which are thought to be due to solution of seaspray salt by infiltrating waters.

Relatively high pH (7.4) and nitrate values indicate a long groundwater flowpath. This flowpath includes a volcanic component giving a moderate calcium, magnesium, and excess sodium content. Low iron content is probably due to the high pH.

Slight deviation from the Meteoric Water Line, relating to a long groundwater flowpath, may be due to the same reasons as the Bull Paddock Spring.

4.4.6 Top Pigeon Bay Spring

The Top Pigeon Bay Spring is situated at an altitude of 360 m at the head of Pigeon Bay Valley, below the Summit Road (Fig. 4.1). It issues from mixed colluvium and is piped for stockwater. Measured discharge lies between 0.7 and 18.8 litres per minute (Appendix 9).

The recharge area lies at an altitude similar to the spring (Figs. 4.8, 4.9). The proximity of this spring to the ridgetop implies that the recharge area may extend horizontally. Infiltration through exposed rock gives a moderate pH (7.0) and low Na/Mg/Ca contents are consistent with a short volcanic groundwater flowpath. A moderate nitrate content is probably due to stock trampling close to the spring.

4.5 SPRING UTILISATION STUDY: THE ANNANDALE WATER SCHEME

Springs are utilised, usually at a small scale, as water supply sources throughout Akaroa County. One of the more ambitious schemes undertaken in the County is on the Annandale property at the base of Pigeon Bay Valley.

A high flow spring (approx. 60 litres per minute) in a tributary of Starvation Gully Stream is tapped to supplement a stockwater scheme on the upper reaches of Annandale farm (Fig. 4.11). Most of the water from this spring, at an altitude of 240 m, is pumped to an altitude of over 600 m at the head of Starvation Gully by a series of four centrifugal multi - stage pumps and adjacent tanks (Fig. 4.12), at a rate of approximately 2000 litres per hour. Water in the tanks triggers the adjacent pump when a specific level is reached and the water is fed to the next highest tank where the same procedure occurs.

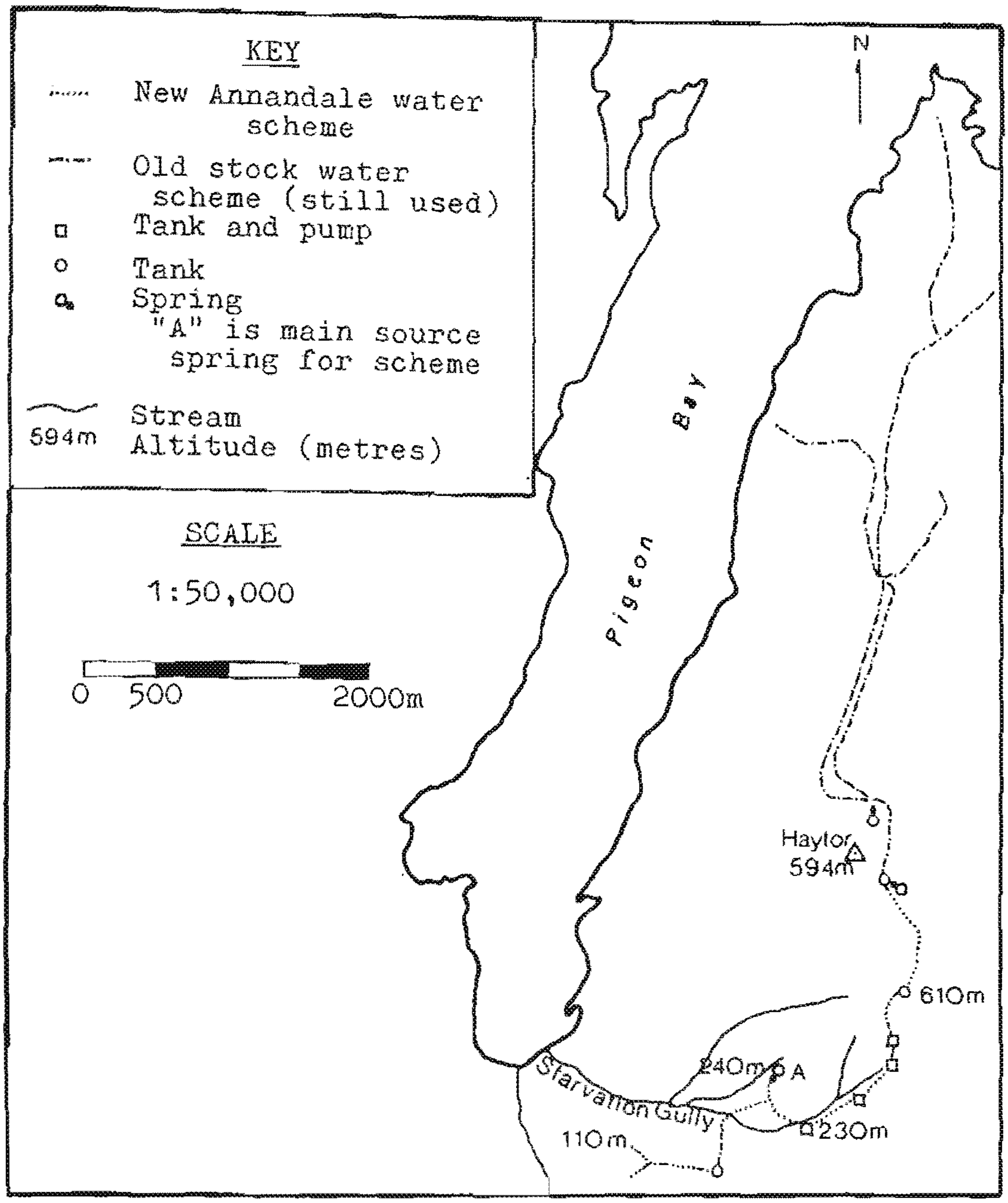


Fig. 4.11 Map showing the Annandale water scheme which draws water from a spring in Starvation Gully (A).

Pumped water from this scheme services 787 hectares of farmland, while 40 hectares of lower land is supplied by gravity fed water from the spring. Pumped water joins the existing stockwater scheme (itself fed from much smaller springs near the ridgetop) at a 910 litre tank near Haytor from where gravity carries piped water to various stock troughs or dams.

Fig. 4.12 Pump and adjacent tank in the Annandale water scheme. Note the exposure of lavas (which show open jointing) in the summit region behind.

4.6 COMPARISON WITH SPRING OCCURRENCE IN FRENCH FARM

Contrary to the theory that spring concentration and discharge would differ from the French Farm area to the Pigeon Bay Valley area observations show that variation is minimal. The number of mapped springs in Pigeon Bay Valley is over double those in French Farm, but this is more a reflection of study area size than the influence of lava flow dip direction. Springs follow a similar distribution pattern in both areas being more common in the higher altitude regions where most rainfall and subsequent recharge is assumed to occur. Springs occur in the same geological situations in both areas, though variation in distribution of surficial deposits means that percentages of springs emerging from the various materials also varies from area to area.

Discharge magnitude is likewise similar in both areas with the majority of springs flowing at less than 2.5 litres per minute. 4% of French Farm springs flow at greater than 15 litres per minute while only 2% of Pigeon Bay springs are in this category. This is opposite to what is expected and may be due to the generally lower discharge, due to seasonal variation, when Pigeon Bay was mapped. Discharge variation follows the same seasonal pattern in both areas, this being the result of the precipitation - infiltration recharge model that appears appropriate.

It is therefore concluded that a hydrogeological model that is appropriate for the springs of French Farm would be equally appropriate in Pigeon Bay Valley. This is probably the result of the generally low dip of lavas and intercalated pyroclastic beds especially at altitude (where springs are concentrated).

4.7 SUMMARY OF SPRING OBSERVATIONS FROM PIGEON BAY VALLEY

1) The importance of relatively impermeable layers in influencing the distribution of springs has become

more evident in Pigeon Bay Valley. These perching layers include, in apparent order of decreasing importance: tuff, tightly or widely jointed lavas, highly weathered lavas, weathered and/or compacted breccia layers, welded or weathered scoria beds, and weathered vesicular lava.

2) Geomorphic benches are commonly capped by one or more of the above layers, and springs are often related to these benches.

3) Springs are most common at the higher altitudes where most recharge appears to occur.

4) Isotope data is consistent with a precipitation - infiltration recharge model.

5) The majority of springs flow at less than 2.5 litres per minute. Only 2% of the mapped springs flow at greater than 15 litres per minute.

6) A seasonal discharge pattern is apparent for the springs.

7) Water quality testing of five Pigeon Bay springs indicates water suitable for drinking water supply.

8) The Annandale water scheme indicates some of the potential for utilisation of spring waters in Akaroa County.

9) The springs of Pigeon Bay Valley show the same distribution and discharge patterns as those of French Farm.

CHAPTER 5

GROUNDWATER MODEL AND MANAGEMENT IMPLICATIONS

5.1 PROPOSED MODEL

In this chapter a groundwater model is presented for the springs of Akaroa County that combines information derived from hydrogeological mapping in French Farm and Pigeon Bay Valley, spring discharge monitoring, and isotope and chemical testing of selected spring waters.

A "head"/storage model in combination with a precipitation - infiltration recharge model is proposed, the "head"/storage model being based on the precept that under natural conditions an aquifer is in a state of dynamic equilibrium (Freeze and Cherry, 1979).

Observation of springs indicates that the associated groundwater is found as irregularly shaped (due to rockmass inhomogeneity) perched water bodies in the lavas of Akaroa County, or as concentrated or dissipated flow within the surficial material. A ready response (commonly within 24 hours) of spring discharge to precipitation is observed and is due to an increased pressure head. Older water held within the lava aquifers is displaced to the springs by newer infiltrating rainwater at the top of the reservoir.

Spring discharge consists of water of a variety of ages. Tritium dating of Rhodes Spring, situated at an altitude of 490 m on the Lyttelton Volcano, determined that drainage represents an age spectrum extending back at least fifteen years (Taylor et al, 1979). An average altitude of recharge of 520 m is approximated for the Rhodes Spring (Stewart et al, 1983) with a catchment extending up to 550

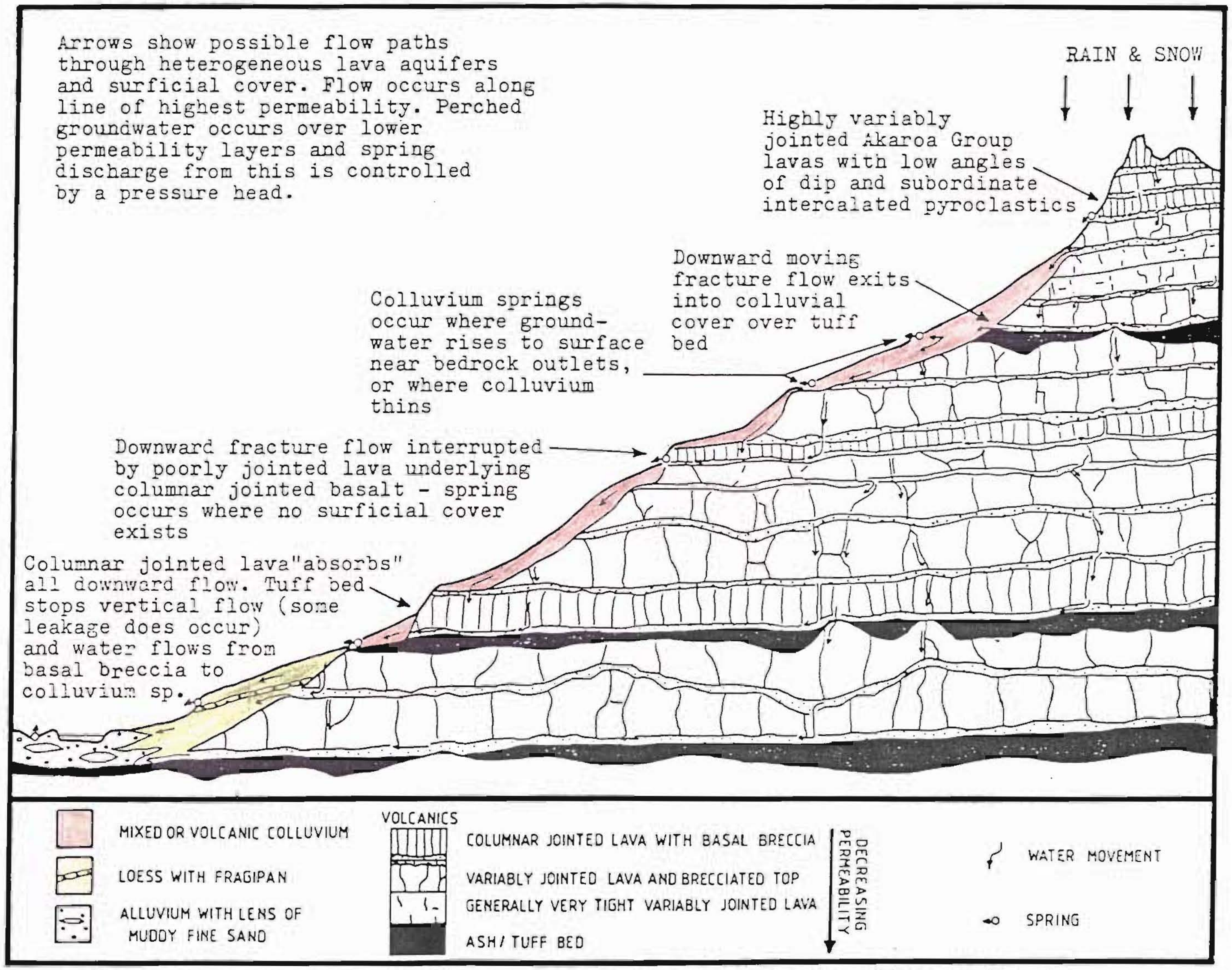
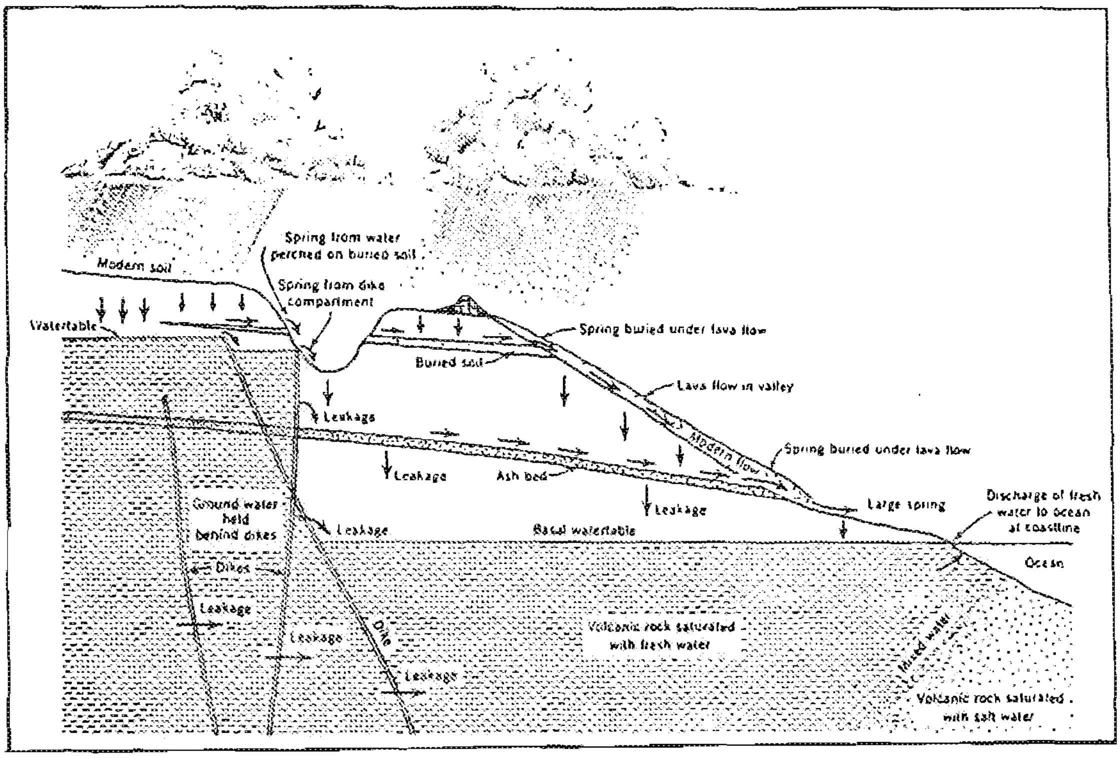


Fig. 5.1 Schematic diagram showing possible flowpaths in the geological materials of Akaroa County.

m. Similar time periods may exist for like flowpaths in Akaroa County, the age of the water being dependent on the permeability of the transmitting medium (determining groundwater flow rates) and the length of the infiltration and groundwater flowpaths (possible flowpaths are shown on Fig. 5.1).

If the infiltrating waters are not trapped on a perching layer they may move downward to an inferred basal groundwater body (Fig. 5.2). The freshwater is expected to be in dynamic balance with salty groundwater beneath the ocean, but no evidence is provided within this study to support this.



<u>Fig. 5.2</u> Circulation of groundwater in highly permeable basalt typical of the Island of Hawaii, showing basal groundwater (beneath the basal water table) of the type inferred to be present, in some form, near sea level in Akaroa Volcanics. The role of dykes in confining groundwater in Hawaii is also shown (from Davis and De Wiest, 1966).

Evidence for infiltration of water to significantly lower altitudes than where precipitation occurred is given by isotope data. Figures 5.3 and 5.4 are plots of oxygen-18 or deuterium contents and altitude of springs from which water samples were taken in Akaroa County. Initially no definite altitude effect (APPENDIX 4) is observed. However, if the lower altitude samples taken at the Nursery, Bottom Glen, and Bull Paddock Springs are assumed to contain drainage waters from higher altitudes, probably near the summit region, then the expected altitude / isotope correlation (APPENDIX 4) is apparent. Consequently it must be inferred that groundwater movement can occur from the summit regions to low altitudes (near sea level) where geological factors permit.

Regression lines drawn on Figures 5.3 and 5.4 are calculated with the exclusion of the three quoted samples. These lines show similar slopes to the isotope / altitude graphs for rainfall in western N.Z. locations (Stewart et al, 1983). For example, rainfall in western locations has δD values that depend on altitude (where h is altitude in metres) thus:

$$\delta D = -0.017h - 30.2$$

while the equivalent regression line in Akaroa County is:

$$\delta D = -0.012h - 43.1$$

One other sample, the Purple Peak Spring, is also anomalous in both of the isotope / altitude plots, but since this spring is derived from a relatively small catchment area, close to a peak, such a variation can be explained by a period of warm rain prior to sampling (T. McTague, Institute of Nuclear Sciences, pers. comm.).

The various aspects of the model are expanded in this chapter, and evidence is presented to substantiate the interpretations made (Table 5.1 is a summary of this information). The implications of this model with respect

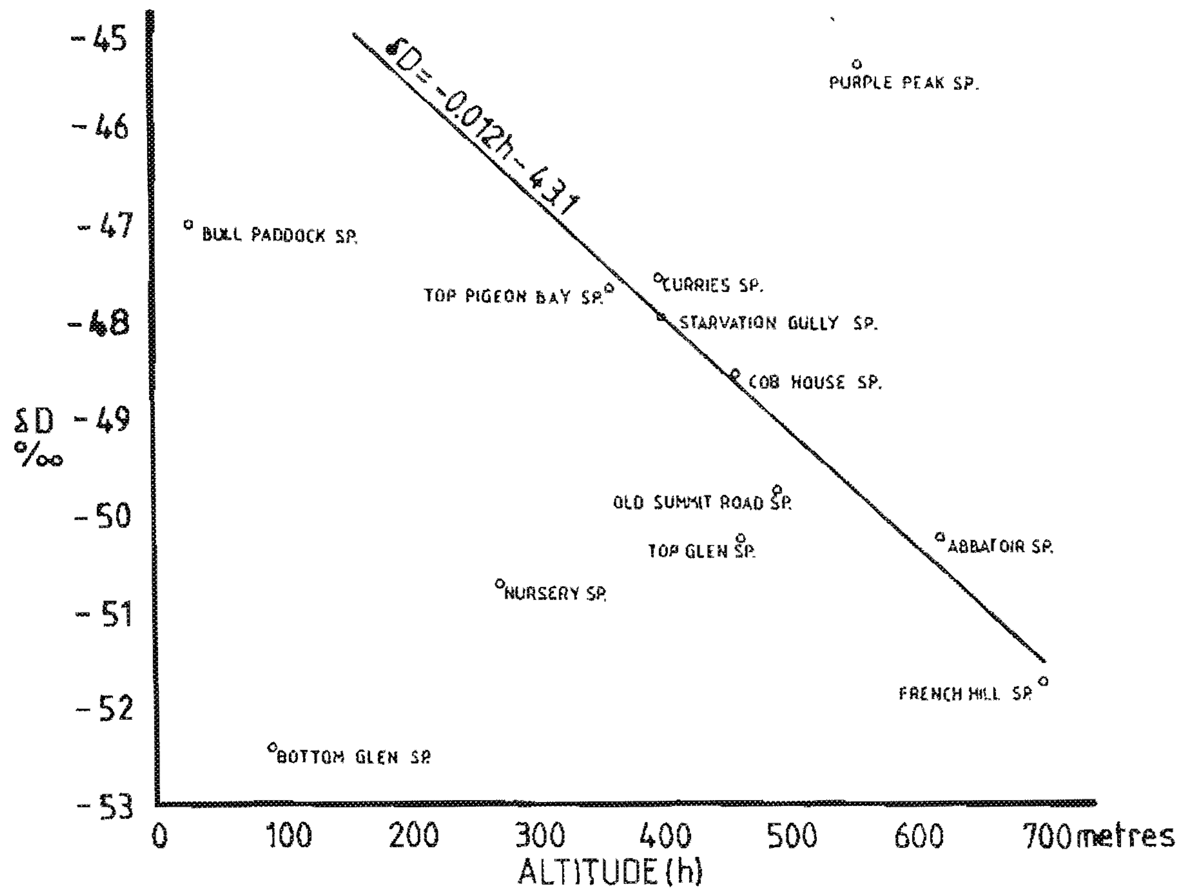


Fig. 5.3 δD values of Akaroa County springwaters (including samples from the catchment of Akaroa County (APPENDIX 4)) plotted against spring altitude. Line is regional regression line.

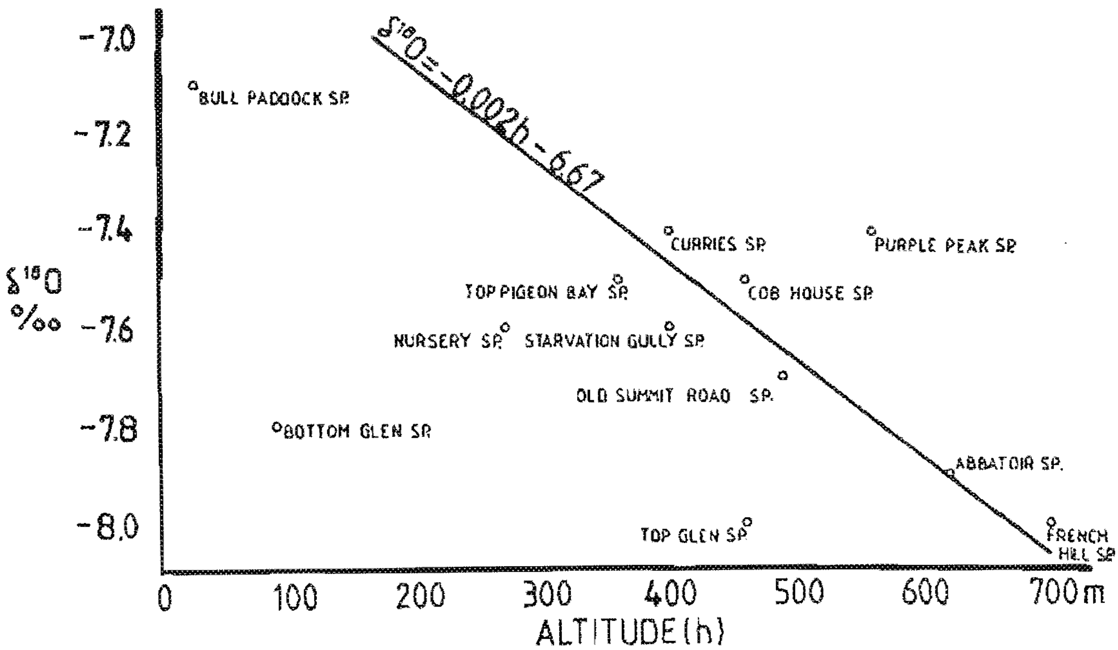


Fig. 5.4 $\delta^{18}O$ values of Akaroa County springwaters (including samples from the catchment of Akaroa township (APPENDIX 4) plotted against spring altitude. Line is regional regression line.

Aspect of Model	Interpretation	Evidence
Recharge	Direct precipitation - infiltration recharge	(i) oxygen-18 and deuterium isotope data (ii) response to local climatic factors
Ground - water movement	1) Groundwater occurs in heterogeneously saturated Akaron Group lavas. Flow is anisotropic - shrinkage cracks provide main vertical flow path, brecciated layers provide horizontal flow path. 2) Perched water bodies and springs often relate to relatively impermeable layers within the volcanic sequence (including tuff and unjointed lava). 3) Surficial deposits often confine ground - water exiting from bedrock aquifers. 4) Groundwater can move from summit regions to near sea level following flowpaths that include lava aquifers and/or surficial cover.	(i) spring observation (ii) oxygen-18 and deuterium / altitude data (iii) chemical data and spring observation
Discharge variability	1) Seasonal spring discharge variability due to evapotranspiration and precipitation fluctuations. 2) Secondary variability related to storm events. 3) Fluctuations related to pressure head effects in response to precipitation and barometric pressure.	(i) monthly spring flow and rainfall over 1 year period (ii) daily spring flow and rain - fall monitoring for 6 weeks (iii) observation by locals
Water quality	1) Temperature range between 8.5 and 15°C. 2) Calcium - magnesium - bicarbonate water.	(i) temperature observation (ii) chemical testing by BSIR

Table 5.1 Summary table of aspects, interpretations, and evidence used to support these interpretations, in the propsed groundwater model.

to management of the springwater resource in Akaroa County are also reviewed.

5.2 GEOLOGICAL CONTROLS ON GROUNDWATER MOVEMENT

5.2.1 Groundwater Movement in Bedrock Aquifers

The principal aquifers in Akaroa County are both heterogeneous and anisotropic, and consist of the variably jointed coherent basalt lavas and their associated brecciated layers. Discontinuities within the lavas contain and transmit groundwater.

Transmission rates vary with aquifer permeability, moving slower through tightly jointed lava (which may show hydraulic conductivities less than 10^{-9} m/s) and faster through open interconnected discontinuities (10^{-2} - 10^{-7} m/s) (Freeze and Cherry, 1979). Water will move preferentially through the relatively permeable zones, and the less permeable rockmass will tend to act in a confining role.

The basalt flows are highly anisotropic aquifers. Shrinkage cracks provide the main vertical flow path, while sub - horizontal joint sets or clast supported basal breccias and unweathered and uncompacted rubbly tops, where interstitial fines are not well developed, are the most efficient media for lateral water transmission.

Lava tunnels, that usually transmit large quantities of water in basalt terrains (Stearns and MacDonald, 1942), are not observed in the rocks of Akaroa County. Lack of vesicle interconnection in vesicular lava tops means that these form perching layers rather than aquifers.

5.2.2 Groundwater Movement in Surficial Materials

Surficial deposits usually confine groundwater emitted from lava aquifers and in the process may become a medium for transmission of the water. Groundwater originating from the volcanics may be supplemented by direct infiltration waters. This water travels through the surficial material until spring discharge occurs (Fig. 5.1) or it is reabsorbed by underlying volcanics. Groundwater flow paths within the various surficial material types are reviewed in Chapter 2.

5.2.3 Barriers to Groundwater Movement

Perching layers observed in Akaroa volcanics include, in decreasing order of importance:

a) tuff/ash beds
b) tightly jointed or massive lavas
c) highly weathered jointed lavas
d) weathered and/or compacted rubbly tops
e) welded/weathered scoria beds
f) weathered vesicular lava

Because of the lateral discontinuity of these perching layers there are regions where water is able to percolate through to a lower groundwater body (Fig. 5.1), be it another perched body or the inferred basal groundwater body.

Components of the Akaroa dyke swarm are assumed to act as barriers to lateral groundwater flow (see French Farm for example). Because of poor exposure little more is known about the hydrogeological effects of these intrusives, and they may form the basis for further study (using drillhole investigation and geophysical methods) since they are known to be of importance in other basaltic settings (Fig. 5.2).

5.3 DISCHARGE VARIABILITY AND QUALITY

5.3.1 Discharge Variability

a) General

The majority of springs in Akaroa County flow at less than 2.5 litres per minute (classified as low flow when mapping (Appendix 3)) with high flow springs (discharge greater than 15 litres per minute) being uncommon. Most high flow springs occur near to the summit, or major ridges of the area, while the majority of springs below the 300 m altitude are low flow. This is thought to relate to the difference in recharge between the two regions.

Flow rates for individual springs show high variability. Spring discharge is determined by three factors (Davis and De Weist,1966):

1) aquifer permeability
2) area contributing to recharge
3) quantity of recharge.

Since the first two factors are fixed it is assumed that spring discharge variability in Akaroa County is related to recharge fluctuation.

Spring variability is defined (Davis and De Weist, 1966) by the equation:

$$Va = [(Q_{max} - Q_{min})/Q_{med}] \times 100$$

where Q_{max} = maximum discharge, Q_{min} = minimum discharge, and Q_{med} = median discharge.

Some representative variabilities as measured over a one year period are presented in Table 5.2.

SPRING	Va (%)	APPROX. ALTITUDE
Abattoir Sp. #1	1780%	620 m
Nursery Sp.	200%	270 m
Bottom Glen Sp.	116%	90 m
Cemetery Sp.	740%	120 m

Table 5.2: Some Representative Spring Variabilities as Measured in Akaroa County Between October, 1984, and September, 1985.

High altitude springs close to the summit area tend to be the most variable. This is due to the dramatic recharge that occurs in these regions in the winter months (Section 5.3.1b) which is in contrast to very little recharge in the summer and autumn periods. This contrast is not as significant at lower altitudes.

The storage capacity of an aquifer will also affect spring variability, eg. a small aquifer will respond quickly to a decrease in recharge with subsequent reduction in spring discharge. This factor may explain the variability of some low altitude springs, eg. the Cemetery Spring (Table 5.2).

b) Seasonal Discharge Variability

Spring discharge follows a seasonal trend which is apparent from monthly flow monitoring(Figs. 3.8, 4.6, 5.6). Such variability is clearly related to recharge (Fig. 5.5) and is consistent with a "head"/storage capacity model. Obvious peak flows in winter lead to the assumption that much of the annual recharge occurs at this time.

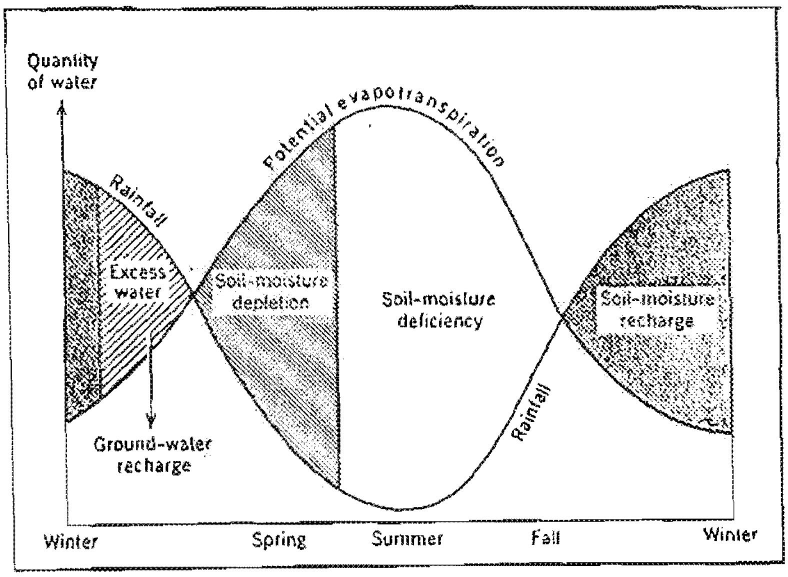


Fig. 5.5 The seasonal effect of potential evapotranspiration on surficial moisture recharge, and consequently on groundwater recharge.

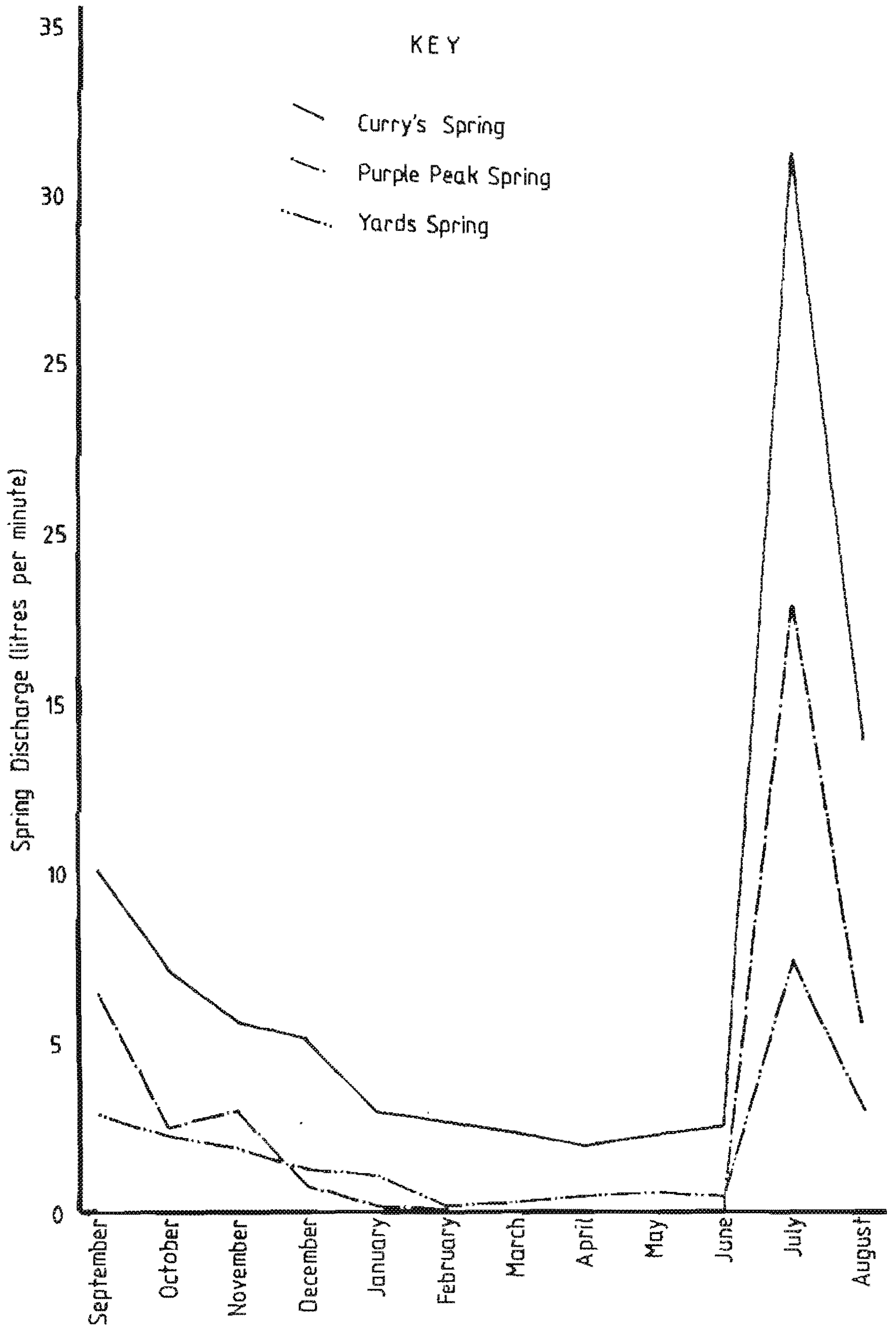


Fig. 5.6 Plot of spring discharge as recorded in the catchment of Akaroa County (see Fig. 5.11, in map pocket) between September, 1984 and August, 1985.

During the spring precipitation is balanced with evapotranspiration leading to little recharge and a general decline in spring flow. In the summer evapotranspiration due to higher temperatures and the drying effect of northwesterly winds removes most of the shallow moisture stored in the surficial cover, though some infiltration may occur through exposed open jointed lavas. With little recharge spring flows continue to decrease in response to a decreasing pressure head in the groundwater bodies that feed them.

The first autumn rains are generally lost directly through evapotranspiration, but as the rains increase and the temperature drops a surplus of water increases the moisture content of the surficial cover. Because of absorption of precipitation water by the surficial material groundwater recharge is minimal at this time.

A warm, dry autumn during the study period resulted in very little groundwater recharge and a general continued decline in spring flow rate. Some springs, for instance the Abattoir springs (Fig. 3.19), display a consistent discharge during this period which may be maintained by water that has been in the rock for long periods of time (Section 5.3.1c).

In winter the surficial moisture content increases beyond the field capacity and water drains downwards into the heterogeneously saturated lavas of the area. A spring discharge maximum occurs during this period. The winter months of June, July, and August are generally the highest rainfall months in Akaroa County (Section 1.3.1) and a dramatic spring flow peak resulted in July of the study period (Fig. 5.6). The August rainfall, being well below average (Otehore (French Farm) values, mean = 184 mm, August 1985 = 108 mm), led to an early flow decline.

c) <u>Discharge Variability Related to Storm Events</u>

Superimposed on this seasonal trend is a secondary discharge variability relating to storm events as observed when daily flow and rainfall monitoring was undertaken at the Abattoir Spring #1 (Fig. 3.20). Significant rainfall is followed by an almost immediate (within 24 hours) upturn in discharge at this high altitude spring. A discharge peak is reached within two to six days after storm cessation, followed by a decline until the next storm commences (see Fig. 5.7 for suggested model).

The time to peak appears to be related to the pre - existing moisture regime in the catchment area. As groundwater levels rise within the rockmass in winter, the vertical infiltration distance for precipitation waters decreases (Fig. 5.7). Since the effect of this infiltrating water is to increase the pressure head on the groundwater body (with a subsequent increase in spring discharge) the spring discharge response time decreases correspondingly.

Response of spring discharge to storm events is also dependent on the geology of the recharge area. The permeability of the geological materials in the recharge area is the major influence on infiltration rate, this determining the time taken for water to percolate from the ground surface to the groundwater body. Where lava with closely spaced, open joints is exposed infiltration is expected to be especially rapid and recharge may occur even in the summer months.

These observations indicate that spring discharge consists of two components:

1) Water related to the storm event which has moved rapidly through the groundwater system (eg. water infiltrating to the groundwater body in close proximity to the spring). This may partly affect the initial upturn in spring discharge, but because of the relatively small recharge area in question this water is likely to be a minor component of discharge.

2) Water not related to the storm event, but which has been moving through the discontinuities of the catchment

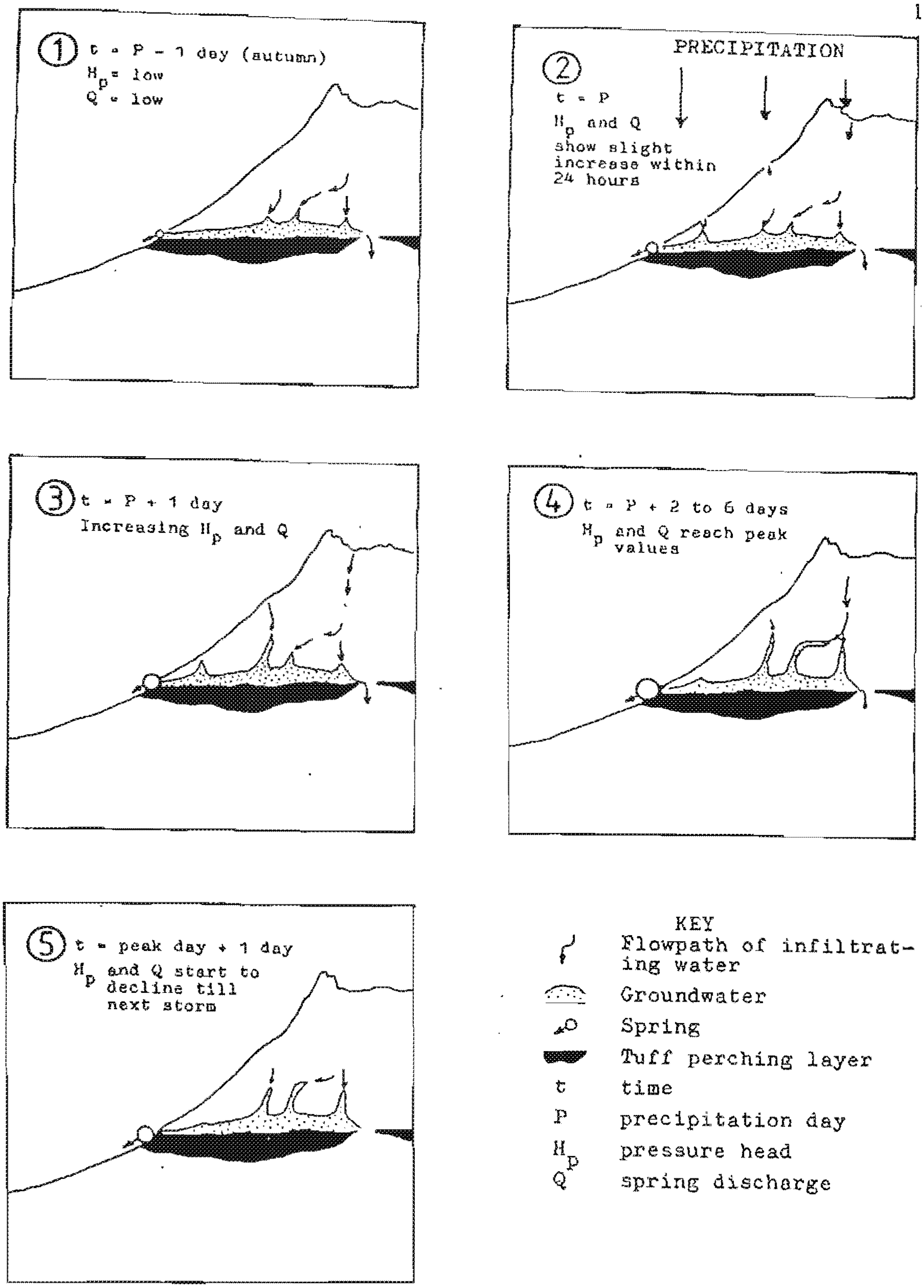


Fig. 5.7 Model to explain response of spring in summit region to storm events. Cartoons show schematic sections through heterogeneously jointed lavas containing a perched water body of irregular shape.

area for periods that may exceed fifteen years. The increased head due to the infiltrating storm water increases the outflow of this water, with variation in infiltration time throughout the recharge area leading to the progressive upturn in spring discharge following the storm event. This older water is thought to be the major discharge component and probably maintains spring flow in dry periods.

d) Atmospheric Pressure Effects on Discharge

Observant farmers in Akaroa County have noted that in times of drought some dry springs may resume flow just before rain. This can be explained by a drop in atmospheric pressure associated with weather patterns.

Changes in atmospheric pressure can produce large fluctuations in hydraulic head in rigid confined aquifers (Freeze and Cherry, 1979), eg. an unweathered basal breccia surrounded by relatively impermeable lithologies. This is an inverse relationship with a decrease in atmospheric pressure causing an increase in hydraulic head, similar to recharge effects, and resulting in spring flow where sufficient increase is felt. The mathematical proof for this effect is found in Davis and De Wiest (1966).

5.3.2 Water Quality

Water quality is a consequence of the natural physical (including temperature) and chemical state of the water, and alterations that may have occurred as a result of human activity. Biological contamination of infiltrating waters is unlikely in Akaroa County because most of the area is low - stocked pastureland, with extensive surficial cover which forms an effective barrier to the infiltration of such contaminants. Consequently water quality testing has been restricted to limited temperature observations, and chemical analysis as performed by the DSIR Chemistry Division (Appendix 5).

a) Temperature

Thermal springs showing temperatures of up to 32°C have been observed in association with the rocks in the north western sector of Lyttelton Volcano (Collins, 1952), but Akaroa Volcano seems to have none, with measured temperatures ranging between 8.5 and 15°C.

Some, especially high altitude springs, remain more or less constantly cold. For instance, temperatures for the Abattoir Spring #1 varied between 8.5 and 9.0°C when measured monthly between November, 1984 and April, 1985. This reflects the generally lower atmospheric temperatures (including wind chill factors) at high altitudes. Others tend to vary in temperature in response to the average atmospheric temperature (measured temperatures for the Starvation Gully #1 Spring ranged between 11.0 and 15.0 degrees).

A relatively long flow path at shallow depths, as in surficial material, influences this responsiveness to atmospheric temperature, since in the upper 10 m or so, diurnal and seasonal variations in air temperature create a zone that is thermally transient (Freeze and Cherry, 1979). Groundwater flowpaths involving greater depths will be insulated from such temperature variations.

b) Water Chemistry

Akaroa springwaters are considered in relation to the Drinking Water Standards for New Zealand (N.Z. Board of Health, 1984) which are summarised in Appendix 5.

Most water from basic volcanic aquifers is suitable for drinking water supply and tends to be calcium - magnesium - bicarbonate water (Davis and De Wiest, 1966). This is confirmed by the results from Akaroa County springwaters that are presented in Table 5.3 (for full analyses see Appendix 5). Observations can be made from these results thus:

Spring	Sample Number	Grid Reference NZMS 260	pH	Aerated pH	Turbidity (NTU units)	Nitrate Nitrogen g/m^3	Chloride g/m^3	Sodium g/m^3	Magnesium g/m^3	Calcium g/m^3	Iron g/m^3	Hardness (as $CaCO_3$) g/m^3
Nursery Spring	KB310	N36 005 147	6.6##	7.9	0.5	0.8	19	16	1.9	7.5	0.10	27
French Hill Spring	KB309	N36 993 154	6.6##	7.7	1.0	0.6	12	9	0.8	5.7	0.26*	18
Abattoir Spring	KB308	N36 989 160	7.0#	7.9	1.2*	0.9	14	12	4.1	8.5	0.21*	38
Bull Paddock Spring	KB339	N36 020 246	7.3 #	8.3	0.4	1.8	61	72	18.0	30.0	0.08	149*
Starvation Gully No 1	KB338	N36 042 242	6.0##	7.6	0.5	3.4	24	19	1.9	6.4	0.16*	24
Bottom Glen Spring	KB341	N36 013 233	7.4	8.3	0.5	4.9	43	49	8.8	18.0	0.10	81*
Top Glen Spring	KB340	N36 997 218	6.8##	7.7	0.2	0.6	20	13	1.5	5.4	0.10	20
Top Pigeon Bay Spring	KB316	N36 018 189	7.0#	7.6	1.5*	1.8	20	16	1.6	5.9	0.10	21
Cob House Spring	KB314	N37 090 092	6.4 ##	7.7	0.8	1.1	16	12	1.1	5.3	0.10	18
Curry's Spring	KB315	N36 103 117	6.1##	7.4	1.0	1.3	18	12	0.8	3.4	0.38	12

This sample does not comply with the following N.Z. standard requirements:

#	Outside desirable range
##	Outside maximum range
*	Exceeds lower guideline limit
**	Exceeds upper guideline limit

Table 5.3 Summary table of chemical analysis results for tested springs in Akaroa County.

1) All tested samples are suitable as drinking water sources.

2) A generally low pH (values between 6.0 and 7.0 are common) places most springs outside the maximum desirable range for drinking water. Aeration brings all waters to an acceptable level however. As a consequence of this acidity it is observed that metal water supply fittings (including hot water cylinders) have a relatively short lifespan. Blue staining of baths and sinks in some Akaroa homes probably results from deposition of copper salts from corrosion of copper pipe.

3) Turbidity values are generally well below the 1 NTU value (Appendix 5) that is desirable. Several springs exiting from mixed colluvium (Abattoir Spring #1, Pigeon Bay Hilltop Spring) exceed this lower guideline limit.

4) Nitrate nitrogen levels lie significantly below the N.Z. Standard limit of $10g/m^3$. This may reflect the absence of intensive fertiliser application or cultivation (eg. cash cropping, peas, green root and forage crops, small seeds and lucerne) and concentrated waste applications (eg. piggery, poultry, and abbatoir wastes) that lead to high nitrate levels in Paparua County (Adams, 1981). Nitrate nitrogen leaching loss will be very low (approximately 5 kg/ha/year, (Adams,1981)) from Akaroa County pastureland.

5) Chloride levels have a maximum value of 61g/cubic metre, less than the $100g/m^3$ highest desirable value, and considerably below the taste threshold that lies between 200 and $300g/m^3$. The highest chloride values are in close proximity to the sea, where the influence of seaspray is suspected.

6) The French Hill Spring, has an aluminium content that exceeds the upper guideline limit. This could lead to water discolouration and deposits.

7) Silica contents (as SiO_2) of tested waters do not exceed guideline values. As a result use of these waters in boiler applications should not result in slake formation.

8) Concentration of iron is often below the lower guideline limit, but four of the ten tested samples exceed this. The high iron content relates to water flow through basalt lava. No values exceed the upper guideline limit and iron content does not preclude any of the samples from drinking water use. The sample from Curry's Spring is high, and associated iron bacteria may form filamentous growths in the reticulation system causing blockages.

9) Nearly all samples are categorised as soft waters with respect to total hardness. Earlier this century Akaroa was the site of a wool scouring industry because of the softness of these waters (Ford, 1949). The Bull Paddock Spring is slightly hard, but as such remains below the upper guideline limit for hardness.

5.4 GROUNDWATER RECHARGE

Evidence obtained in this study confirms that a direct precipitation - infiltration recharge model is correct for the groundwater that discharges as springs in Akaroa County.

5.4.1 Isotope Data

Oxygen-18 and deuterium contents of groundwater derived from direct infiltration of local precipitation, when plotted together (Fig. 5.8), will lie on or near the Meteoric Water Line (Stewart and Taylor, 1981) which is typical of New Zealand rainfall and is defined by the equation:

$$\delta D = 8.0\delta^{18}O + 13$$

Much summer precipitation is returned to the atmosphere by evapotranspiration (Section 5.3.1 b), which is essentially

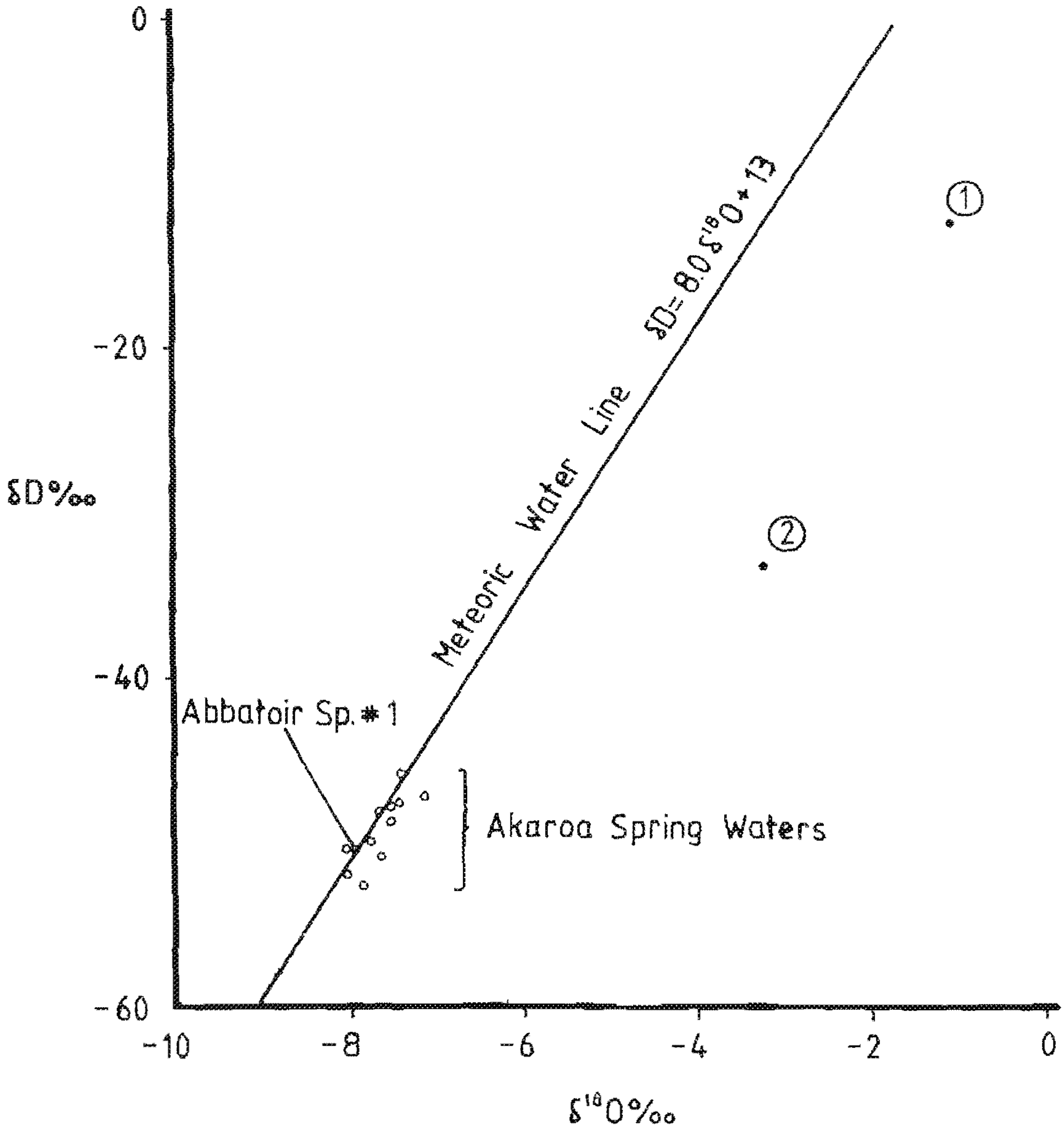


Figure 5.8 Plot showing proximity of Akaroa County springwaters to the N.Z. Meteoric Water Line. Sample 1 is lake water and 2 is deep geothermal water, both from the North Island (based on Stewart and Taylor, 1981). These are included for contrast.

non - fractionating (Appendix 4); as a result recharge water is composed mostly of winter precipitation, rather than of mean annual precipitation, but it will still lie on the Meteoric Water Line.

Oxygen-18 and deuterium values for twelve springs within Akaroa County (enumerated in APPENDIX 4) plot very close to the Meteoric Water Line (Fig. 5.8), confirming that local precipitation is the source of the groundwater. Slight deviations of some of the plotted points from the Meteoric Water Line may be due to several reasons (Gat, 1971) including:

(i) chemical interaction of water with aquifer materia , involving isotope exchange which changes $\delta^{18}O$.

(ii) isotope separation during water transport (mainly diffusion).

Representative examples of New Zealand lake water and deep geothermal water (from Stewart and Taylor, 1981) are inserted for comparison and clearly plot away from this line.

5.4.2 Rainfall/Spring Discharge Data

The responsiveness of spring discharge to local climatic factors including rainfall, as outlined in Section 5.4.1, confirms isotope evidence for precipitation as the recharge source.

5.4.3 Spring Permanence

The year - round flow of most of the Akaroa springs, including many in the summit regions, can be explained using the proposed model. The springs are fed by groundwater that is being transmitted and stored in the rockmass. When no recharge is occurring there is depletion of these groundwater bodies by discharge at associated springs.

Where groundwater storage volumes are small depletion may be such that the associated springs dry up. However, when aquifer volume is sufficient springs will flow throughout the year, though at a decreased rate when recharge is not occurring, due to a lowering pressure head.

To maintain groundwater levels that are adequate for year - round spring flow sufficient annual recharge is required. Two factors are invoked to account for the recharge quantities needed, especially in the summit regions where recharge areas appear relatively small, to maintain year - round spring flow. These factors are the high precipitation rates of the area, and the fast infiltration rates that some of the geological components of the area allow.

Precipitation

A relatively high precipitation rate in Akaroa County (mean annual rainfall of greater than 900 mm) compares with a mean annual rainfall of 589 mm as recorded at the Botanic Gardens in central Christchurch. Rainfall distribution as summarised on Fig. 1.3 shows a general increase with altitude (for instance, in the French Hill area there is a mean annual rainfall of approximately 1400 mm) suggesting that the greatest potential for recharge occurs in the summit regions. Assuming that 30% (Section 1.3.1) of the annual rainfall happens in the winter months when most of the annual recharge occurs, and that 50% of this percolates to groundwater, then there is a potential yearly recharge of 21,000 litres from an area 10 m x 10 m in the French Hill area.

As a result of the greater recharge that occurs in the summit regions most of the springs in French Farm and Pigeon Bay Valley lie at altitudes above 250 m to 300 m.

Infiltration

Initial infiltration occurs through surficial deposits or may find direct entry into bedrock where no surficial cover exists. The rate of infiltration will determine, in part, how much precipitation is lost to the atmosphere through evapotranspiration.

Where exposed, mostly in the summit regions, jointed lavas are expected to show permeabilities between 10^{-2} and 10^{-9} m/s (Freeze and Cherry, 1979). Actual permeability measurements for the lavas have not been undertaken in this study because of financial constraints, but may be appropriate in future investigations.

Those with higher permeabilities, ie. lavas showing open, closely spaced joints, are visually observed to absorb a high proportion of precipitation falling on them. This, in combination with the low dip of the local lava flows (offering a surface with more vertical joints per unit area than steeply dipping lavas) is partly responsible for the significant recharge contribution from the rocky summit regions.

Recharge areas may be laterally extensive. Some ridgetops show exposed jointed lava over distances of several kilometres, thus forming large recharge areas that may only supply a small number of springs. The presence of springs only short vertical distances below the summit ridges in this high rainfall area can thus be explained.

Infiltration occurs through all of the surficial materials described in Chapter 2. The rate and amount of infiltration that results is determined by the permeability of the deposits and their slope angle. In situ permeabilities determined for surficial deposits lie between 1.1×10^{-5} m/s (a gravelly volcanic colluvium) and 1.6×10^{-7} m/s (a compact mixed colluvium with high loess content), with a general infiltration rate increase with increase in coarse volcanic component (Table 2.2). The distribution of surficial materials, with relatively permeable mixed and volcanic colluvium more common at altitudes greater than 250 to 300 metres, is such that there is greater potential for recharge through the surficial deposits at these higher elevations.

Slope angle will determine to some extent how much water is lost to surface runoff. Lower slope angles are more conducive to infiltration since water will more readily sit on the surface allowing infiltration through surficial deposits to proceed.

5.5 MANAGEMENT IMPLICATIONS

5.5.1 Water Quality Implications

a) Water Chemistry

The adequacy of the Akaroa County springwaters for drinking, general domestic, and agricultural applications is confirmed by chemical analyses and present widespread utilisation. Some suggestions relating to water chemistry include:

1) Reticulation systems should incorporate facilities to bring pH values into a more acceptable range (7.4 to 8.5) to prolong the life of metal fittings. This may involve aeration of the water, or addition of soda ash (sodium carbonate, Na_2CO_3). The use of non - metal (eg. PVC) pipes is recommended where possible.

2) Reduction of turbidity values that exceed Standards guidelines (usually where water emerges from springs in colluvium) may be undertaken by installation of a silt trap in the reticulation close to the spring. This is illustrated in Figure 4.10. Should this not be effective, addition of alum ($KAl(SO_4)_2.12H_2O$) will assist in forming a flock with the silt particles which can then be filtered out.

3) If turbidity or filamentous bacterial build - up occurs due to excessive iron contents removal should be undertaken using aeration of the water followed by

filtration.

4) Protection of water quality in the source aquifer must be exercised (Fetter, 1980). Critical to preventing groundwater pollution is identification of the aquifer recharge area using isotope and chemical data (Appendices 4 and 5) and geological interpretation. It is recommended that chemical water quality is monitored where potential sources of contamination (eg. rubbish tips, cemeteries, abattoirs) exist in the identified recharge area.

b) Water Temperature

Springwater temperature ranges in Akaroa County make for palatable drinking water, although the low temperatures of some springs (eg. 8.5 to 9.0°C at the Abattoir #1 Spring) may decrease the efficiency of water treatment processes should they be needed.

5.5.2 Recharge

The implications of a precipitation - infiltration recharge model are twofold:

1) the springwater resource will respond to precipitation and evapotranspiration fluctuations (Section 5.3.1). For example, flows will decrease in a drought year, in the same way as most stream flows. Consequently determination of the safe yield from a spring will require calculation of annual recharge using precipitation data and evapotranspiration data (Section 5.5.4c).

2) recharge is dependent on local climatic and geological factors alone.

5.5.3 Discharge Magnitude and Variability

The suitability of a spring as a potable water source is dependent to an extent on its discharge magnitude with respect to the size of the demand. Where individual springs are not sufficiently large to provide for the demand it may be necessary to draw water from a number of sources. As an example, a domestic supply in Starvation Gully is fed by four springs each flowing at less than 2.5 litres per minute (Section 4.3.2).

The high discharge variability demonstrated by monitored springs (Section 5.3.1) would suggest that discharge monitoring should be initiated when considering utilisation of specific springs for water supply. Methods for testing discharge used in this study are outlined in Appendix 9. Flow readings taken once a month for a one year period, and preferably for a three to five year period, are recommended to provide the general discharge fluctuation pattern for individual springs. Minimum discharge rates have been shown to occur in the late summer to early autumn period (February to April) and monitoring during these months should give a good indication of lowest flows. Since precipitation varies from year to year relevant rainfall data should also be taken into account when considering spring magnitude.

5.5.4 Springwater Abstraction Methods and Safe Yield

A method for withdrawal of water from colluvial springs for small scale water supplies (eg. single house supplies using approximately 550 litres/person/day (Akaroa County Council approximation)) has been demonstrated in Section 4.3.2. This method is popular in rural areas and is generally adequate in such applications.

On a slightly larger scale, involving flows of about 30 litres per minute, nursery irrigation (Section 3.3.3) and large stockwater (Section 4.4) supplies have been developed using single springs that have a relatively high flow for this region (up to 40 and 60 litres per minute respectively). Because of seasonal discharge variability however, the nursery supply has reached low flows of about 7 litres per minute (April, 1985), and plans to supplement this with water from a second spring are to be implemented.

For larger scale applications (eg. a settlement, such as Pigeon Bay) it may be necessary to increase spring discharge by increasing aquifer permeability. This may involve physical enlargement of the spring exit by excavation or by tunnelling into a bedrock aquifer showing a spring exit. Depletion of the aquifer is the risk in such development and is discussed in Section 5.5.4c (Safe Yield).

At all scales it is important that springwater is drawn from as close to the spring as possible, and preferably underground, to avoid contamination by stock excrement and coliform bacteria.

a) Spring Excavation

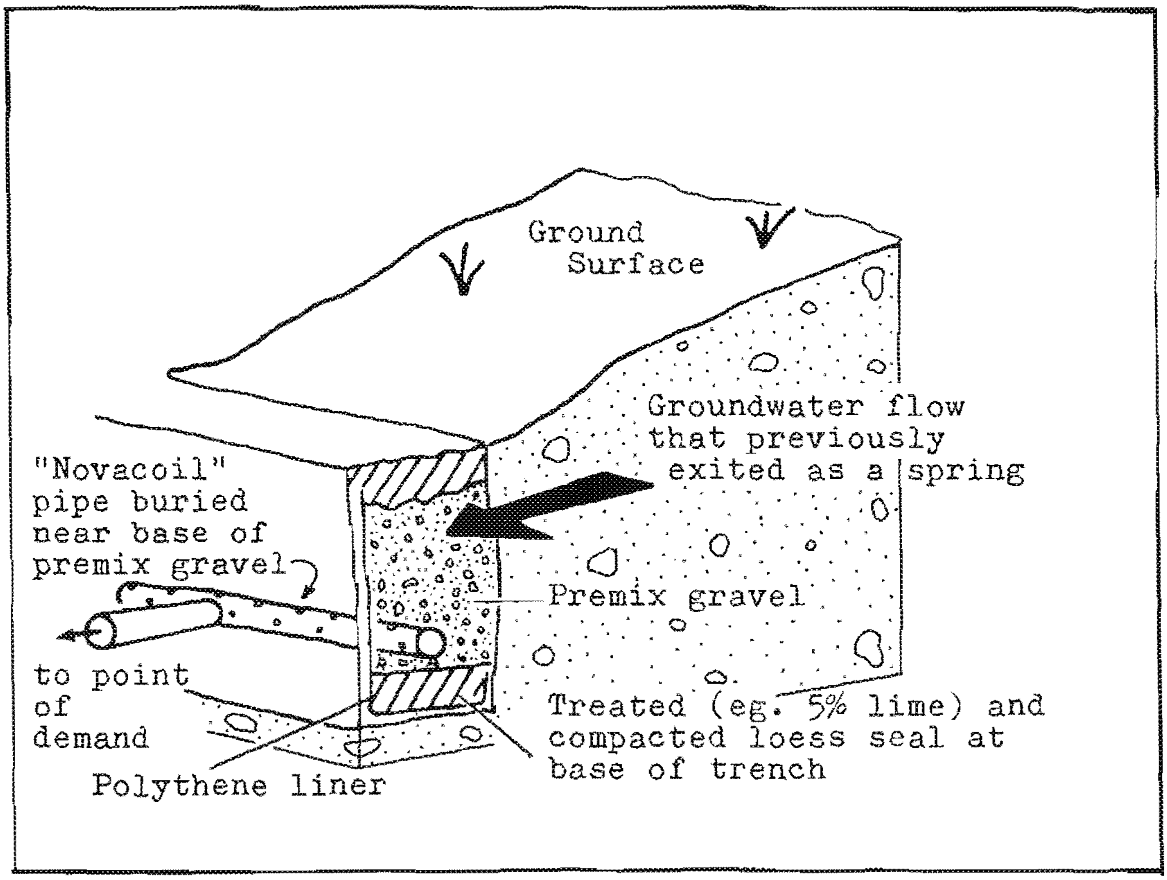


Fig. 5.9 Method for increasing spring flow at exit using excavation of a trench across line of groundwater flow and subsequent collection of water using "Novacoil" perforated pipe. NB. "Novacoil" should be below level of original groundwater flow and slope towards unperforated pipe that carries water to point of demand.

Figure 5.9 shows a possible model for water supply development using excavation of a spring. This may be applied for both colluvial and bedrock springs where excavation will improve permeability. The excavated area is lined with an impermeable substance, eg. agricultural grade polythene, sealed with compacted, stabilised (eg. using 5% lime) loess, and filled with gravel ("pre-mix" gravel and sand will allow filtration of silt and clay sized particles). "Novacoil" pipe is buried in this gravel near its base in an appropriate orientation to intercept water flow. This pipe is connected to the water supply line. The gravel is subsequently covered with relatively impermeable material, such as treated and compacted loess (as above), as a precaution against stock or bacterial contamination.

b) Collection Adits/Horizontal Drillholes

In the geologically similar Hawaiian Islands collection tunnels and horizontal drillholes have been successfully used to recover groundwater which is perched on ash and tuff layers. The scale and potential of the groundwater resource is dramatically greater in Hawaii however (with an mean annual rainfall of 6350 mm on Oahu (Fetter, 1980)) and special attention must be paid to safe yield (Section 5.5.4c) if these methods are utilised.

The driving of horizontal adits (about 2 m deep) into, and at the top of, tuff or scoria beds that are acting as perching layers for a lava aquifer (Fig. 5.10), may be feasible. These beds will allow for relatively easy excavation, and if this intersects the base of the lava aquifer then water should flow towards the adit or drillhole. Orientations should approximate the dip of the top of the perching bed.

Adits intersect a large number of joints in the overlying lava, and it is possible to ensure that no impermeable material is left between the excavation and the aquifer which would impede water flow into the adit. As a consequence, however, support for the adit roof is removed, and artificial support may be needed to stop roof collapse. A relatively thick tuff or scoria bed is required, since adits require a depth of at least 2 metres for construction access, and this will restrict the locations where this method is suitable. The base of the pyroclastic bed must not be penetrated or leakage to underlying lithologies may result.

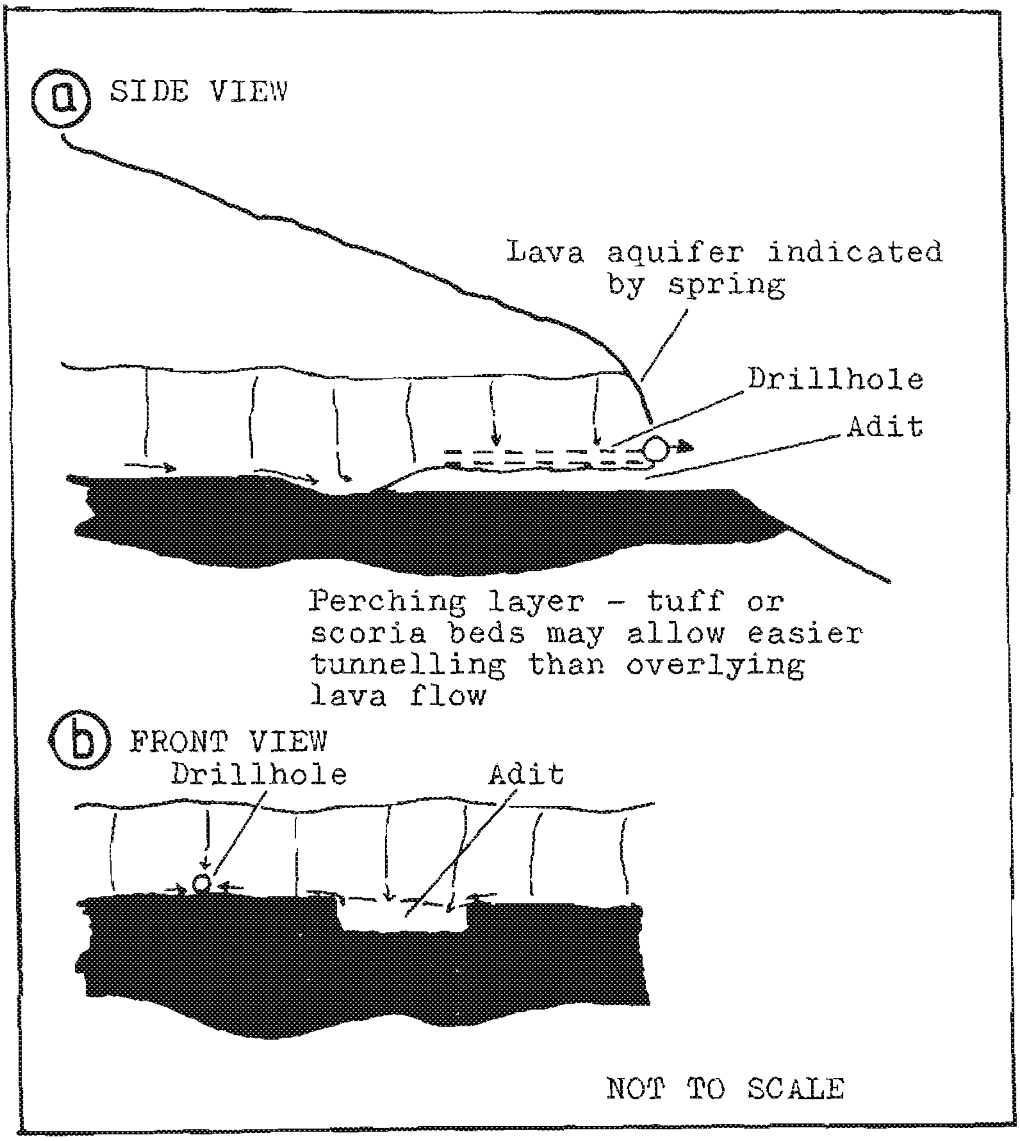


Fig. 5.10 Suggested location and form of horizontal adits or drillholes to draw water from lava aquifers.

Horizontal drillholes bored into lava material close to an underlying perching layer (Fig. 5.10) will not intersect as many aquifer joints as an adit and will generally have a lower yield. A lower cost is the advantage of this method however.

c) Safe Yield

In developing the springwater resource of Akaroa County the concept of safe yield must be taken into account. Safe yield is the amount of water which can be removed regularly and permanently without dangerous depletion of the storage reserve (Fetter, 1980). Safe yield will not lead to a decrease in quality of the existing groundwater store, and will protect the existing local water rights and environment.

To maintain a safe yield annual abstraction should normally not exceed annual recharge. The natural recharge to an undeveloped aquifer feeding a spring may be determined by a water - budget analysis of the recharge area (Fetter, 1980):

$$\text{eg. } R = P - (E + Q_s)$$

where R = recharge
P = precipitation
E = evapotranspiration
Q_s = surface runoff

For accurate calculation of recharge the parameters in the above equation, including evapotranspiration (eg. using a lysimeter) must be measured in the recharge area. Such measurements have not been undertaken in this study and it is considered that water balance analysis of selected spring catchments should form the basis of future investigations.

d) Springwater Abstraction Case Study: Akaroa Township

Akaroa township is of special interest with respect to spring development for water supply since this is where demand is highest (approximately 1.42 million litres per day in peak summer period (Akaroa County Council figures)). Akaroa township receives its present water supply from two reservoirs (Fig. 5.11) fed by Aylmers, Balgueri, and Grehan streams. There is a summer minimum flow of 1.83 million litres per day from these three sources (A.C.C.) and storage of 3.41 million litres, ie. about three days supply. Actual minimum flow is normally recorded in early autumn (Appendix 10) reflecting spring flow data (Figure 5.6), and suggesting that the streams are mainly spring fed in periods of low rainfall.

The above figures indicate that there is limited water available for future expansion of the township. Consequently Steven, Fitzmaurice and Partners (civil and public health engineers) have been commissioned by the A.C.C. to investigate potential methods of increasing the volumes of potable water available to Akaroa township. Preliminary investigations have centred around increasing the discharge of the springs that feed the three main catchment streams, and especially Aylmers and Balgueri streams. A map of the springs in the catchment of Akaroa township (Figure 5.11, in map pocket) has been produced to assist in such studies. Spring distribution and discharge variability is consistent with the proposed model.

Initial findings are that spring flow may often be increased in summer by simple excavation of the spring exit with a shovel or crowbar. The Cob House Spring (Fig. 5.11), one of the three biggest springs in Balgueri Stream, nearly doubled in flow (visual estimation) after 5 minute's digging in December, 1985. It is assumed therefore, that stream flow may be increased in the summer period by such small scale excavation in the source springs. To maintain the aquifer supplies it may be necessary to include valves at the larger springs to be closed at times when demand is not high. Further investigations are proceeding and will involve calculation of safe yield.

5.6 RECOMMENDED FUTURE WORK

The following lines of future investigation are recommended and are aimed at supporting aspects of the proposed groundwater model that remain unproven and providing information useful for future development of the groundwater resource of Akaroa County:

1) Piezometric monitoring of a perched groundwater body in combination with spring monitoring to test pressure head control of spring flow. If a confined aquifer, eg. a basal breccia over- and underlain by less permeable beds, is selected then barometric pressure effects may also be monitored.

2) Tritium dating of Akaroa County springwaters to test the spectrum of ages present.

3) Regular (eg. 3-monthly) springwater sampling to be tested for oxygen-18 and deuterium content to determine any seasonal fluctuation in isotope values.

4) Borehole and geophysical investigation on the role of the Akaroa Dyke Swarm in groundwater flow. This may involve drilling in known localities where intrusions interrupt groundwater flow, eg. on the eastern side of Pulpit Rock.

5) Borehole investigation to below sea level to test for the presence of a basal groundwater body.

6) Water budget analysis of selected spring catchments to determine the feasibility of development of the related aquifers for water supply (eg. using adits or horizontal boreholes).

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 GEOLOGICAL OCCURRENCE OF SPRINGS

Hydrogeological models for springs are the result of observations made during hydrogeological mapping of French Farm and Pigeon Bay Valley at a 1:10,000 scale.

It is concluded that groundwater discharge occurs at springs and seeps whose form and distribution are geologically controlled. Relatively impermeable beds (eg. tuff) within the volcanic sequence are most influential in determining spring distribution. Discharge may occur directly from bedrock aquifers, but more commonly is through the extensive surficial cover.

6.2 GROUNDWATER MODEL FOR THE SPRINGS

A groundwater model based on observation of associated springs is proposed for Akaroa County. This is based on interpretations of the data gathered during hydrogeological mapping, isotope and chemical analyses of selected springwaters (leading to interpretations of groundwater movement and recharge), and spring discharge monitoring.

A "head"/storage model is proposed for groundwater occurrence associated with the springs. In this model water is stored and transmitted in heterogeneous lava aquifers. Water held within these aquifers is displaced to springs by infiltrating rainwater at the top of irregularly shaped reservoirs. Consequently spring discharge consists of water with an age spectrum that may extend back more than fifteen years (Taylor et al, 1979), this age being dependent on flow path length and the permeability of the transmitting materials.

Groundwater recharge occurs through infiltration of local precipitation with the greatest potential for recharge occurring in the summit regions. Groundwater flowpaths can exist from the summit regions to near sea level, with transmission occurring through lava materials and surficial deposits.

6.3 SPRING DISCHARGE QUANTITY

The majority of springs in Akaroa County flow at less than 2.5 litres per minute. Springs flowing at greater than 15 litres per minute are uncommon.

Monthly discharge monitoring of 18 springs has been undertaken for a one year period to determine annual fluctuations. Daily monitoring, for a six week period, of a spring in the summit region to determine more minor fluctuations has also been performed.

All measured springs show a high degree of discharge variability (Abattoir Spring #1 shows 1780% variability when monitored over a one year period). A seasonal recharge pattern is reflected in spring discharge. Dramatic peak flows occur in winter (in July during the study period) followed by a steady decline in discharge throughout the rest of the year. Lowest measured discharge occurred during March, April, and May of the study period, ie. the autumn months. Discharge at this time is maintained by water stored in the lavas.

Superimposed on this seasonal trend is a secondary discharge variability relating to storm events. Springs in the summit region respond to storm events within 24 hours and reach a discharge peak within 2 to 6 days after the storm. This pattern is consistent with the "head"/storage model.

6.4 GROUNDWATER QUALITY

The adequacy of the Akaroa County springwaters for potable water is confirmed by chemical analysis and present widespread utilisation, though consideration of water treatment to counteract possible acidity, turbidity, and excess iron problems may be necessary if spring development for water supply occurs.

6.5 MANAGEMENT IMPLICATIONS

1) The high discharge variability demonstrated by monitored springs would suggest that discharge monitoring should be initiated when considering utilisation of specific springs for water supply.

2) Several methods for utilisation of springs are outlined. These range from simply piping water away from spring exits to excavation of aquifers associated with springs to increase yield.

3) Safe yield determinations (eg. using water budget analysis of the spring recharge area) must accompany such developments so that dangerous depletion of the storage does not occur.

4) Protection of water quality in the source aquifer must also be exercised with monitoring of chemical quality where potential sources of contamination occur in the identified recharge area.

ACKNOWLEDGEMENTS

I'd like to say a heartfelt thank you to the people who have helped and supported me during this study:

to the North Canterbury Catchment Board for providing funding, and especially to Bob Ayrie who was always friendly and helpful when I called in;

to Mr D.H. Bell who maintained his composure as he read my drafts;

to the staff of the Ministry of Works who supplied me with expensive dye (for free), a raingauge, a Foxboro water level meter, and friendly advice;

to the staff at the Institute of Nuclear Sciences and the DSIR Chemistry Division who tested my water samples and provided insights and interest in the results;

to Julie who is one of my best friends and for whom I will always have a deep affection. We had some great times in Ak., and she turned a study on springs into a lesson on ~~eating~~ life;

to the people in Akaroa who were always great to see and so good to us, including Bill and Dorrie, Ted and Doll, the Brocheries, Merv, Bayview Motors, and Calvin and Gwen;

to the people back in town: including Jay, Dee, Druce, Paul, who are my mates and were always good to come back to;

to P.K. for praying with me, and the rest of Dev. Inc. (Bud, Lovell, Yeti, Glasseye, and Slugger Doug) who are cool;

to Mum and Dad who are the best parents around and have been so generous during the study period;

and to Mike and Julie, Rob, Dee, Andrea, and Glennis who were there to help when the pressure was on.

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APPENDIX 1

ROCK AND SOIL MATERIAL DESCRIPTION

APPENDIX 1

ROCK AND SOIL MATERIAL DESCRIPTION

Rock and soil material descriptions follow the proposed engineering geological format outlined in Bell and Pettinga (1984) and depicted in Figures A1.1 and A1.2 (overleaf). The conciseness of this scheme, and its ease of use in field situations, were both significant advantages over other classification schemes in common use e.g. N.Z. Geological Survey (1977).

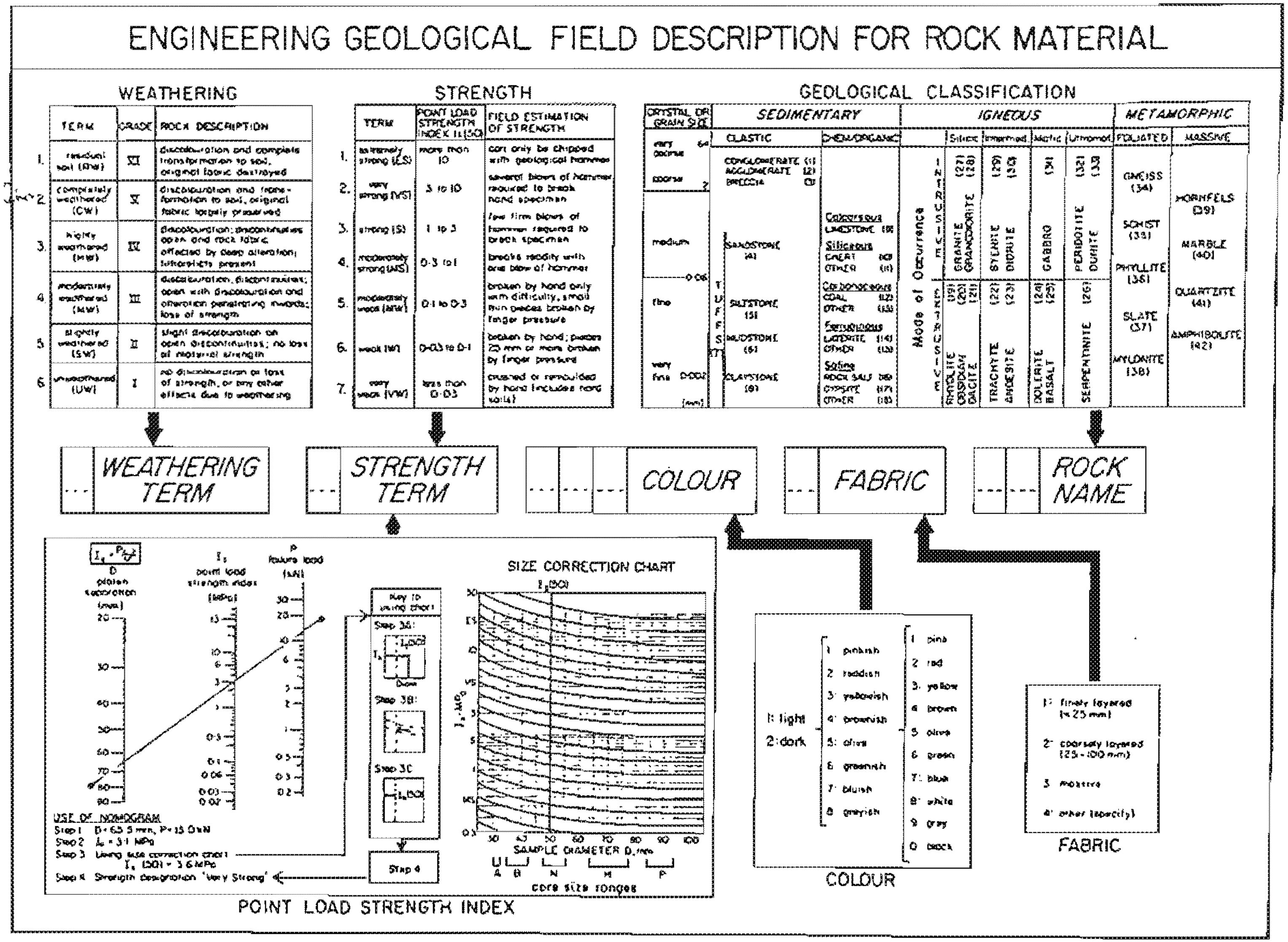
ENGINEERING GEOLOGICAL FIELD DESCRIPTION FOR ROCK MATERIAL
WEATHERING
TERM
GRADE
ROCK DESCRIPTION
1. residual soil (RW) VI discolouration and complete transformation to soil, original fabric destroyed
2. completely weathered (CW) V discolouration and transformation to soil, original fabric largely preserved
3. highly weathered (HW) IV discolouration; discontinuities open and rock fabric affected by deep alteration; lithorelicts present
4. moderately weathered (MW) III discolouration, discontinuities open with discolouration and alteration penetrating inwards; loss of strength
5. slightly weathered (SW) II slight discolouration on open discontinuities; no loss of material strength
6. unweathered (UW) I no discolouration or loss of strength, or any other effects due to weathering
STRENGTH
TERM
POINT LOAD STRENGTH INDEX I(50)
FIELD ESTIMATION OF STRENGTH
1. extremely strong (ES) more than 10 can only be chipped with geological hammer
2. very strong (VS) 3 to 10 several blows of hammer required to break hand specimen
3. strong (S) 1 to 3 few firm blows of hammer required to break specimen
4. moderately strong (MS) 0·3 to 1 breaks readily with one blow of hammer
5. moderately weak (MW) 0·1 to 0·3 broken by hand only with difficulty, small thin pieces broken by finger pressure
6. weak (W) 0·03 to 0·1 broken by hand; pieces 25 mm or more broken by finger pressure
7. very weak (VW) less than 0·03 crushed or remoulded by hand (includes hard soils)
GEOLOGICAL CLASSIFICATION
SEDIMENTARY
IGNEOUS
METAMORPHIC
CLASTIC
CHEM/ORGANIC
FOLIATED
MASSIVE
WEATHERING TERM
STRENGTH TERM
COLOUR
FABRIC
ROCK NAME
SIZE CORRECTION CHART
SAMPLE DIAMETER D, mm
core size ranges
USE OF NOMOGRAM
POINT LOAD STRENGTH INDEX
1: light
2: dark
COLOUR
FABRIC

Fig. A1.1

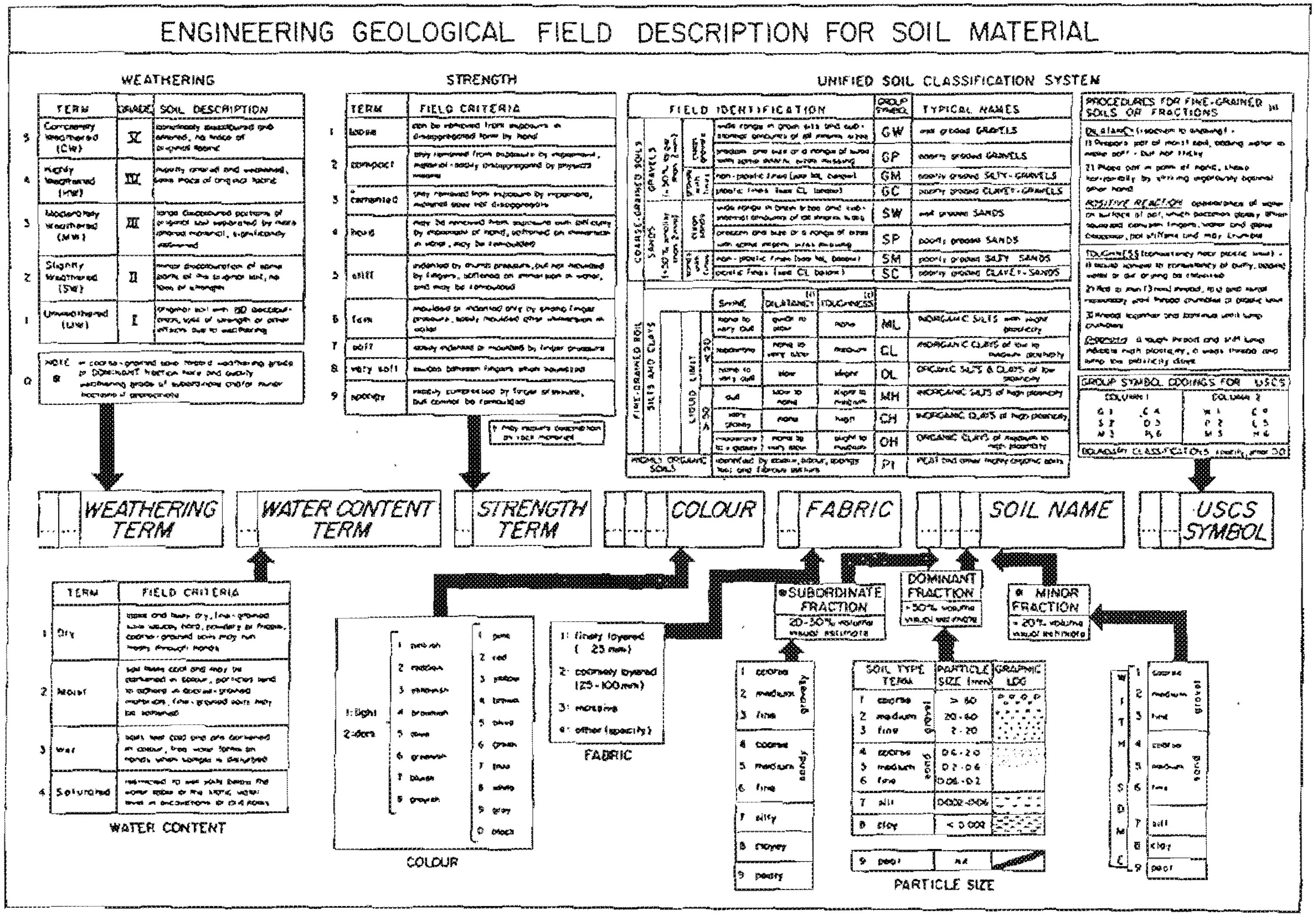
ENGINEERING GEOLOGICAL FIELD DESCRIPTION FOR SOIL MATERIAL
WEATHERING
STRENGTH
UNIFIED SOIL CLASSIFICATION SYSTEM
WEATHERING TERM
WATER CONTENT TERM
STRENGTH TERM
COLOUR
FABRIC
SOIL NAME
USCS SYMBOL
SUBORDINATE FRACTION
DOMINANT FRACTION
MINOR FRACTION
WATER CONTENT
COLOUR
FABRIC
PARTICLE SIZE

Fig. A1.2

APPENDIX 2

PREVIOUS WORK

APPENDIX 2

PREVIOUS WORK

A2.1 BEDROCK GEOLOGY

Haast (1879) provided the first documentation of the geology of Banks Peninsula. Speight subsequently published 21 papers on the geological aspects of the Peninsula. Speight (1944) gives a general account of the geology of Akaroa in which he discusses the form of the volcano and its intrusive bodies.

Stipp and McDougall (1968) published a number of K/Ar dates from Akaroa Volcano indicating that volcanic activity occurred between 9.0 and 8.0 Ma.

Evans (1970) made palaeomagnetic measurements and K/Ar age determinations from a sequence of lavas on Akaroa Volcano. The tested lavas were extruded over a time interval from 9.1 - 8.4 Ma, and seven magnetic reversals are recorded.

Thesis work by Falloon (1982) involved mapping, stratigraphic, petrographic, and geochemical studies of Akaroa volcanics in the Onawe - French Farm - Wainui area. He determined that the Akaroa Volcano Main Dome consisted dominantly of phyric basalts, aphyric basalts and hawaiites with subordinate mugearites and benmoreites. These lie on a basement of trachytic flows, tuffs and breccias, intruded by the gabbro and syenite of Onawe Peninsula.

Recent work on the geology of Banks Peninsula has included that of Sewell (1985) who has reinterpreted the geology from studies he has undertaken in the central Peninsula region. Geochemical studies on Akaroa Volcano by C. Dorsey (University of Canterbury) have yet to be completed, while a review of Banks Peninsula geology has been published in the form of a guidebook (Weaver et al, 1985).

A2.2 SURFICIAL DEPOSITS

Numerous authors have published papers dealing with the origin and nature of the loessial and volcanic bedrock derived deposits that mantle Banks Peninsula. Haast (1879) was one of the first authors to mention the loess mantle and he was followed by others including Raeside (1964), Griffiths (1973), Bell (1980), and Bell and Trangmar (in prep.).

Bell and Trangmar (in prep.) have discussed in depth the origin, nature, and hazards of the regolith materials of the Port Hills which are similarly found in Akaroa County.

A2.3 HYDROGEOLOGY

Collins (1952) has discussed the presence and distribution of the thermal waters of Banks Peninsula, posing questions as to their source. The thermal springs occur in the north western sector of Lyttelton Volcano with Collins observing none in Akaroa volcanics.

Bell and Trangmar (in prep.) have mentioned the presence of groundwater seepages and flow in the regolith materials of the Port Hills. Observations as to the distribution of these groundwater occurrences within the regolith material are also recorded.

Yetton (1983) undertook one of the first hydrogeological studies in this region in the Purau - Port Levy area in which he has proposed a model for spring occurrence relating to the geology.

APPENDIX 3

HYDROGEOLOGICAL MAPPING

APPENDIX 3

HYDROGEOLOGICAL MAPPING

Field hydrogeological mapping of French Farm and Pigeon Bay valleys at 1:10,000 scale was undertaken between November, 1984 and July, 1985. The springs in the catchment of Akaroa township were mapped at the same scale, for management purposes, in December, 1985.

Field information was recorded on overlays taped to black and white aerial photographs enlarged to 1:10,000 scale. The relevant air photographs belong to the SN 2860 series issued by New Zealand Aerial Mapping. The photograph numbers are:

Pigeon Bay:	M41, M42, M43
	N41, N42, N43, N44
French Farm:	O41, O42, O43
	P41, P42, P43
Akaroa:	P44, P45, P46
	Q32, Q33

These were run in September of 1975 and show conditions following a damaging storm in August of that year. Colluvial springs often appear as dark patches in the lighter dry areas and thus the aerial photographs are a useful aid in locating these springs. Stereoscopic inspection of the photographs is useful in locating bedrock outcrop (usually associated with abrupt slope changes). Bedrock outcrop gives a reasonable idea of the volcanic structure of the area.

Distribution of surficial material has been mapped on the hydrogeological maps because of its importance in determining infiltration rates and control and location of spring exits. Boundaries are only approximate and should not be used for engineering purposes without further investigation.

For mapping purposes springs have been classified according to discharge magnitude and the geological materials from which they are observed to flow. This material is not necessarily the water source as a bedrock origin is suspected for much of the water that emerges as springs in colluvial material. Five spring lithologies are determined: bedrock, volcanic colluvium, mixed colluvium, loess (including loess colluvium), and alluvium. Volcanic perching layers observed in association with these lithologies are also recorded. Streams flowing year - round are mapped as are those showing seasonal or intermittent flow of significance.

To maintain consistency with the study of Yetton (1983) spring discharge is subdivided into three size ranges, these being:

a) low flow : discharge less than 2.5 litres per minute;
b) medium flow : discharge between 2.5 and 15 litres per minute;
c) high flow : discharge greater than 15 litres per minute.

Short - lived ephemeral springs have not been mapped in this study.

Because of the high discharge variability of the Akaroa County springs these ranges are useful to show relative size within an area at the time of mapping, but may not be accurate throughout the year. For instance, a spring classified as "low flow" in autumn may have to be reclassified as "medium flow" in winter.

Those springs that have been of special interest in this study, and have been monitored or tested, have been named by this author for ease of reference. These names will generally not be known to the locals though they usually have local significance.

Streams showing year - round flow have been mapped as have those with seasonal or intermittent flow where it is considered that these may relate to springs.

APPENDIX 4

STABLE ISOTOPES IN AKAROA GROUNDWATER STUDIES

APPENDIX 4

STABLE ISOTOPES IN AKAROA GROUNDWATER STUDIES

A4.1 REFERENCES

STEWART, M.K., TAYLOR C.B. 1981: Environmental isotopes in New Zealand hydrology. 1. Introduction: the role of oxygen-18, deuterium, and tritium in hydrology. N.Z. Jl. of Sci., 24: 295-311.

STEWART, M.K., COX, M.A., JAMES, M.R., LYON, G.L. 1983: Deuterium in New Zealand rivers and streams. Inst. Nuclear Sci., INS-R-320, 32 pp.

TAYLOR, C.B., STEWART, M.K. 1979: Isotopic identification of sources of groundwater in Canterbury: Present status of programme. IN Noonan, M.J. Ed. The quality and movement of groundwater in alluvial aquifers of New Zealand. Lincoln College Press, Canterbury, New Zealand. pp 59-72.

A4.2 THEORY

The stable environmental isotopes oxygen-18 and deuterium (D) have been used as indicators of springwater source and altitude of recharge in Akaroa County.

Natural water consists of approximately 99.8% H_2O (molecular weight = 18), 0.2% $H_2{}^{18}O$ (M.W.=20), and 0.016% HDO (M.W.=19). As evaporation of liquid phase water occurs fractionation of deuterium and oxygen-18 also takes place. As water vapour rises and cools some condensation occurs leading to precipitation. Since the D/H or $^{18}O/^{16}O$ ratios are higher in the liquid phase than in the vapour phase, ratios in atmospheric vapour become progressively lower as cooling proceeds and precipitation is removed. The general trend is, therefore, towards a lower concentration of oxygen-18 and deuterium as altitude of precipitation increases.

Isotope contents are recorded as a δ-value which is the difference in parts per thousand between the isotopic ratios ($^{18}O/^{16}O$ and D/H) and that of an internationally accepted standard (Vienna Standard Mean Ocean Water) ie.,

$$\delta D\text{‰} = \frac{(D/H)_{sample}}{(D/H)_{standard}} - 1 \times 1000$$

The lighter H_2O evaporates easier than HDO or $H_2{}^{18}O$ and so precipitation tends to have lower heavy isotope content than parent ocean water, ie. most -values are negative. Assuming altitude is the only factor affecting springwater isotope composition in the study area then the more negative the -value the greater the elevation at which the source water was precipitated. Groundwater tends to be a mean of isotopic composition of precipitation of the recharge area. As a result a very general indication of altitude of recharge can be gained by graphing isotopic composition against altitude eg. for this study strong deviations from the main cluster of graphed points has been used as an indicator of recharge at a very different altitude to which the relevant spring occurs. "Isotopic altitudes of recharge" have been calculated for springs in various areas (eg. Fontes and Zuppi, 1976), but seasonal variation due to temperature means that inaccuracies result if isotope readings are limited in number.

Precipitation derived groundwater shows oxygen-18/ deuterium isotope ratios that lie close to a line known as the Meteoric Water Line (MWL). Slight deviations of springwater from the isotopic composition of recharging rain and therefore, the MWL, can be explained by several reasons:

a) chemical interaction of water with aquifer materials, involving isotope exchange which changes δO;

b) geographic displacement by surface flow (water falls as precipitation at another location);

c) isotope separation (diffusion) during transport;

d) isotope composition can be heavier if infiltrating rain undergoes some evaporation while passing through the soil and aerated zones;

e) water derives from evaporating surface water bodies such as lakes or swamps;

f) mixing with other waters (eg. seawater intrusion, subsurface brines);

The latter two can generally be discounted for the subaerial springs of Akaroa County.

Other possible sources of groundwater such as connate and plutonic water will deviate from this Meteoric Water Line.

A4.3 METHOD

Water from twelve springs, of varying altitude, locality, size, and geological setting have been been tested by the New Zealand Institute of Nuclear Sciences. Deuterium and oxygen-18 contents have been determined.

Sampling involves the collecting of 30ml of water in a glass bottle with a rubber - sealed metal cap. It is important to avoid evaporation of the sample. Relevant information to be recorded includes date of sampling, spring flow rate, map grid reference, and altitude.

A4.4 RESULTS

Values for oxygen-18 and deuterium contents, and associated relevant details are summarised in Table A4.1.

A4.5 CONCLUSIONS

1) The $\delta\,^{18}O$ and δD values plot close to the meteoric water line

$$\delta D = 8.0\,\delta\,^{18}O + 13$$

which is typical of New Zealand rainfall. This, therefore, indicates that a precipitation - infiltration model will explain the origin of these waters.

2) When plotting D against altitude most samples plot close to a line showing an altitude slope similar to that of the equation derived for New Zealand rainfall isotope composition

$$\delta D = -0.017h - 30.2 \quad \text{(h is altitude in metres)}$$

although well below this line due to the rainout effect on the east coast of the South Island. This indicates a definite altitude effect in Akaroa County.

3) Anomalies occur with respect to altitude when considering the three low altitude springs known as Bull Paddock, Nursery, and Bottom Glen. However this can be reconciled if it is assumed that these springs are probably drainage waters from higher altitude rainfall in the region of Starvation Gully #1, French Hill, and Top Glen springs respectively. Purple Peak Spring is less negative than expected, but this can be explained by a period of warm rain prior to sampling.

4) The Bull Paddock, Nursery, and Bottom Glen springs are slightly anomalous to the meteoric water line (MWL) but this may be explained by either chemical

Results: Dates of sampling: 2-5 November, 1984.

Spring Name	INS File No.	Spring Flow Rate (Litres per min.)	Map Reference NZMS 260	Altitude	$\delta\ ^{18}O$	δ D
Cob House Sp	HC 565	180.0	N37/090 092	460m	-7.5	-48.5
Curry's Sp	566	7.0	N36/103 117	400m	-7.4	-47.5
Purple Pk Sp	567	2.4	N36/106 102	560m	-7.4	-45.5
Starvation Gully 1 Sp	568	2.8	N36/042 242	400m	-7.6	-47.9
Bull Paddock Sp	569	6.7	N36/020 246	25m	-7.1	-47.0
Bottom Glen Sp	570	20.0	N36/013 233	90m	-7.8	-52.4
Top Glen Sp	571	18.0	N36/997 218	460m	-8.0	-50.2
Top Pigeon Bay Sp	572	13.2	N36/018 189	360m	-7.5	-47.6
Old Summit Rd Sp	573	4.7	N36/003 193	490m	-7.7	-49.7
Abattoir 1 Sp	574	75.0	N36/989 160	620m	-7.9	-50.2
French Peak Sp	575	30	N36/993 154	700m	-8.0	-51.7
Nursery Sp	576	29.4	N36/005 147	270m	-7.6	-50.7

Table A4.1 Summary table of isotope results.

interaction of the water with the aquifer materials or isotope separation (diffusion) during transport.

APPENDIX 5

CHEMICAL TESTING OF AKAROA COUNTY SPRINGWATERS

A5.1 Groundwater origin and flowpath determination using chemical composition.

A5.1.1 Theory

A5.1.2 Method

A5.1.3 Results

A5.2 Chemical water quality

A5.2.1 Theory

A5.2.2 Method

A5.2.3 Results

APPENDIX 5

CHEMICAL TESTING OF AKAROA COUNTY SPRINGWATERS

A5.1 GROUNDWATER ORIGIN AND FLOWPATH DETERMINATION USING CHEMICAL COMPOSITION

A5.1.1 Theory

Chemical components of groundwater are potentially important in the interpretation of the geologic history of water. Without chemical analysis it is not possible to deduce whether studied water is an active cycling groundwater, or of marine, evaporative, connate, magmatic or other origin. This does not mean however that a definite origin can always be determined. Generally a low salt content points towards simple rain infiltration, but a medium to high salt concentration points to a more complicated history (Mazor, 1976).

Various elements and compounds that are useful source indicators for groundwater in volcanic terrain are reviewed here.

a) pH

Carbon dioxide trapped or produced in the soil zone is the main source of hydrogen ions. These hydrogen ions are used (and therefore pH increases) as they react with bedrock minerals, eg. feldspar. A low pH may therefore indicate percolation through the soil layer followed by a short flowpath through the underlying bedrock.

b) Nitrate Nitrogen

Most nitrate in natural water is derived from organic sources or from downward leaching of agricultural chemicals. Nitrate is generally enriched with length of flowpath especially under pastureland.

c) Bromide

Bromide is a minor component of most natural waters. Where a chlorine:bromine ratio of close to 300 exists a marine origin may be suspected.

d) Chloride

Chlorides are a minor constituent of the earth's crust but a major constituent of most natural water. Possible sources in Akaroa are:

1) concentration by evaporation of chloride contributed by rain or snow;
2) seawater contribution including that of airborne salts from seaspray. These salts may dissolve in surface water as it percolates into the subsurface.

Chlorides are not a significant constituent of silicate rocks and therefore there is no tendency toward development of this facies as groundwater moves along basalt flow paths.

e) Calcium

Calcium is a common ion in subsurface water. In a volcanic environment weathering releases calcium from plagioclase feldspar and various pyroxene groups. High calcium contents may therefore indicate a long volcanic flowpath. Calcite infilling may result if pH increases.
Where there is significant seawater influence there may be about five times as many magnesium ions as calcium.

f) Magnesium

Sources of magnesium are the weathering of olivine and augite as well as saltwater influence, and as such may be an indicator of length of flowpath.

g) Sodium

Sodium is derived from seawater aerosol and excess may be derived from the weathering of silicates such as sodium-rich plagioclase feldspar.

h) Iron

In low pH waters iron may derive from, for instance, augite, magnetite, or olivine, to be transported as oxides or hydroxides. Therefore, in a basalt environment iron may be a good length-of-flowpath indicator dependent on pH.

i) Manganese

In natural waters the concentration of manganese is less than half that of iron, but it is a similar flowpath length indicator since most is released through weathering of minerals.

A5.1.2 Method

Water samples (10) were collected from springs selected using the criteria presented in Appendix 4. All springs that have been chemically tested have also been tested for isotopic content (oxygen-18 and deuterium).

The procedure for collection of water samples for chemical analysis is outlined by the DSIR Chemistry Division who perform the analysis. Provided sampling kits consist of 3 sample bottles:

1) 100 ml bottle, containing neutral preservative (mercuric oxide).

2) 500 ml bottle, containing acid preservative (distilled hydrochloric acid).

3) 500 ml bottle, containing no preservative.

Each of these bottles must be filled whenever a sample is taken - the three bottles together constitute one sample.

Analysis is subsequently performed in relation to the New Zealand Standards for Drinking Water.

A5.1.3 Results

Results as for A5.2.3.

A5.2 CHEMICAL WATER QUALITY

A5.2.1 Theory

The chemical and biological characteristics of water determine its usefulness for drinking water. Akaroa springwaters are considered in relation to the Drinking Water Standards for New Zealand (N.Z. Board of Health, 1984) which are based on two criteria:

1) The presence of substances with adverse physiological effects (Table A5.1).

2) The presence of objectionable tastes, odours, or colours (Table A5.2).

Inorganic Constituents of Health Significance

Constituent[a]	Unit[b]	Guide-line value	Remarks	Document Reference: N.Z. Standards	Document Reference: WHO Guide-lines Vol. 1
arsenic	g/m^3	0.05			4.2.2.1
boron	g/m^3	0.5	safe level for human intake is 5 g/m^3, but some glass-house plants are damaged above 0.5 g/m^3	4.2.2	4.2
cadmium	g/m^3	0.005			4.2.2.5
chromium	g/m^3	0.05	total chromium		4.2.2.6
cyanide	g/m^3	0.1			4.2.2.7
fluoride	g/m^3	0.9 to 1.1	deliberately added fluoride	4.2.3	4.2.2.8
lead	g/m^3	0.05			4.2.2.10
mercury	g/m^3	0.001			4.2.2.11
nitrate	g/m^3(N)	10	above the guideline value health of bottle-fed infants is likely to be at risk		4.2.2.13
selenium	g/m^3	0.01			4.2.2.14

[a] Constituents of possible health significance not in the table are discussed in Section 4.2.
[b] g/m^3 = mg/l = p.p.m. (parts per million).

Table A5.1 Table from N.Z. Standards for Drinking Water (N.Z. Board of Health, 1984) showing guideline values for chemical components of water of health significance.

Aesthetic Quality

Constituent or characteristic	Unit[a]	Guideline values: Highest Desirable	Guideline values: Excessive	Undesirable effect that may be produced	Document Reference WHO Guidelines Vol. I
aluminium	g/m^3	0.05	0.2	discolouration and deposits; possible corrosion association; special precautions required for renal dialysis	4.4.3.1
chloride	g/m^3	100	250	corrosion, taste threshold between 200 and 300 g/m^3	4.4.3.2
chlorobenzenes and chlorophenols	no guideline value set			these compounds can affect taste and odour	4.3.7.5 & 4.3.7.6
colour	true colour units (TCU)[b]	5	30	discolouration and trouble with chlorination	4.4.3.3
copper	g/m^3	0.05	1.0	astringent taste, discolouration and corrosion of pipes, and utensils	4.4.3.4
hardness	g/m^3 (as $CaCO_3$)	80	200	excessive scale formation, electric element burn-out	4.4.3.5
hydrogen sulphide		not detectable by consumer		taste and odour	4.4.3.6
iron	g/m^3	0.1	1.0	taste, turbidity, discolouration, deposits, growth of iron bacteria	4.4.3.7
manganese	g/m^3	0.05	0.5	taste, turbidity, discolouration, deposits in pipes	4.4.3.8
pH range	-	7.4 to 8.5	7.0 to 8.5	corrosion and scale, unsatisfactory disinfection	4.4.3.10
sodium	g/m^3	100	200	taste	4.4.3.11
solids (total dissolved)	g/m^3	500	1 000	taste	4.4.3.12
sulphate	g/m^3	50	400	corrosion, laxative effect when magnesium present	4.4.3.13
taste and odour	-	-	-	inoffensive to most consumers	4.4.3.14
temperature	-	c	c	no guideline values set	4.4.3.16
turbidity	nephelometric turbidity units (NTU)	1	5	discolouration; preferably less than 1 NTU for disinfection efficiency	4.4.3.15
zinc	g/m^3	5	5	taste, discolouration, deposits	4.4.3.17

[a] g/m^3 = mg/l = p.p.m. (parts per million).

[b] True colour is the colour of the water from which the turbidity has been removed. It is measured by the platinum-cobalt standard method.[11]

[c] Cool water is generally more palatable. Low water temperature tends to decrease the efficiency of water treatment processes, including disinfection. High water temperature encourages growth of nuisance organisms and intensifies taste, odour, colour and corrosion problems.

Table A5.2 Table from N.Z. Health Standards for Drinking Water (N.Z. Board of Health, 1984) showing guideline values for chemical components of aesthetic significance.

The effects of various chemical components on the quality of potable water supplies are reviewed here.

1) pH. The highest desirable pH values lie within the range 7.7 to 8.5. Where pH is outside this range corrosion and scale in metal water supply fittings may result. Unsatisfactory disinfection may also occur. Acid pH values can often be made more favourable through aeration of the water. Some dissolved carbon dioxide, which often lowers pH, is lost to the atmosphere in this process.

2) Turbidity. The presence of fine silt and clay in water imparts a cloudiness called turbidity. The highest desirable value for turbidity in New Zealand drinking water is 1 NTU (nephelometric turbidity unit) which relates to the amount of light the sample absorbs. An excessive limit of 5 NTU has been imposed.

Where not removed from the water excessive silt and clay will cause discolouration and may lodge in pipes and tanks increasing maintenance costs. Suspended particles may also provide a medium on which bacteria may be carried. For disinfection efficiency a value of less than 1 NTU is preferred.

3) Nitrate Nitrogen. Nitrate nitrogen occurs naturally in many waters. This may be supplemented by sources such as fertiliser, sewage, effluent, and nitrogen - fixing plants. Nitrates fixed by, eg. legumes, are commonly in excess of the plants' needs, so a surplus is available for leaching.

Nitrate nitrogen has proved to be a health hazard when it occurs in drinking water at concentrations in excess of 10 g/m^3 causing impairment of the blood's ability to transport oxygen. The resultant condition known as methemoglobinemia occurs in foetuses and infants under the age of three months (Vigil, 1965).

4) Chloride. The New Zealand Standard for Drinking Water gives a highest desirable value for chloride at 100 g/m^3 with the excessive limit at 250 g/m^3. Shallow groundwater in regions of heavy precipitation generally contains less than 30 ppm of chloride.

Excess chloride content may cause corrosion, while a taste threshold occurs between 200 and 300 g/m^3. Such contents may reflect contamination by sea spray, seawater, or sewage.

5) Aluminium. The highest desirable aluminium content is 0.05 g/m^3 and the excessive value is 0.2 g/m^3. Excess aluminium can cause discolouration and deposits. Contrary to popular opinion, based on unscientific information, aluminium is not a poison in water supplies (Davis and De Wiest, 1966).

6) Silica. Silica in solution does not affect the potability of water, but is of importance if water is to be used in boilers. Most commonly groundwater contains between 5 and 40 ppm SiO_2. Excessive silica can be removed by demineralisation or else specific boiler treatment compounds are used to prevent scale formation.

7) Iron. Iron in drinking water imparts a metallic taste at concentrations of 1.8 g/m^3 (Cohen, 1960), while soluble iron at concentrations in excess of 0.3 g/m^3 can stain surfaces (Fetter, 1980). Consequently a water quality criterion for iron of 0.1 g/m^3 has been suggested for domestic use to avoid objectionable staining of plumbing fixtures, with an upper guideline limit of 1.0 g/m^3.

8) Hardness (as $CaCO_3$). The amount of calcium, magnesium, and iron contribute to the hardness of

water. These cations react with soap to form a precipitate, thus reducing the cleansing action of the soap. The hardness of water is expressed as that due to the equivalent amount of calcium carbonate. Nearly all waters possess temporary and permanent hardness. Temporary hardness due to bicarbonates of calcium and magnesium is removed by boiling as the calcium and magnesium are precipitated by the loss of carbon dioxide. Permanent hardness is usually due to calcium and magnesium sulphates but chlorides and nitrates may also contribute.

Hardness is classified thus:

50 ppm of hardness - soft
50 - 100 ppm of hardness - moderately soft
100 - 150 ppm of hardness - slightly hard
150 - 250 ppm of hardness - moderately hard
250 - 350 ppm of hardness - hard
350+ ppm of hardness - very hard

A5.2.2 Method

Sample collection and testing as for A5.1.2.

A5.2.3 Results

Results obtained by the DSIR Chemistry Division in water quality testing of 10 springs and one well are presented on the following six pages.

The following symbols are used on the data pages:

a) The letters LT mean "less than".
b) This sample does not comply with the following N.Z. Standard requirements:

outside desirable range
outside maximum range
* exceeds lower guideline limit
** exceeds upper guideline limit

DSIR CHEMISTRY DIVISION CHRISTCHURCH

SUPPLEMENTARY WATER REPORT

N2129
N2130

Supply : BANKS PENINSULA WATER SOURCES
Sampling location : KB 308 ABBATOIR SPRING NO. 1
Sampling location : KB 309 FRENCH HILL SPRING
Taken : 4/3/85 Received : 6/3/85 Reported : 21/8/85

Inspector's No. :	KB 308		KB 309	
ANALYSIS				
Units g/m3, except pH or unless otherwise stated.				
pH	7.0	#	6.6	##
pH after aeration	7.9		7.7	
Acidity to pH 8.3 (as CO2)	12		6	
Total Alkalinity to pH4.5 as HCO3	54		23	
Alkalinity to pH 8.3 (as CO3)	NIL		NIL	
Turbidity (NTU units)	1.2	*	1.0	
Absorbance units (270nm, 1cm cell)	0.009		0.007	
Chemical Oxygen Demand (as O)	3		LT 2	
Ammoniacal Nitrogen	0.016		0.019	
Nitrite Nitrogen	0.001		0.002	
Nitrate Nitrogen	0.90		0.61	
Soluble Phosphate (as P)	LT 0.1		LT 0.1	
Sulphate	2.6		2.3	
Bromide	0.15		LT 0.05	
Chloride	14		12	
Fluoride	0.06		0.08	
Calcium	8.5		5.7	
Magnesium	4.1		0.84	
Potassium	LT 0.38		LT 0.38	
Sodium	12		9.0	
Total Silica (as SiO2)	18		22	
Aluminium	LT 0.25		0.36	**
Arsenic	LT 0.10		LT 0.10	
Boron	LT 0.01		LT 0.01	
Chromium	LT 0.01		LT 0.01	
Cobalt	LT 0.03		LT 0.03	
Copper	LT 0.03		LT 0.03	
Iron	0.21	*	0.26	*
Lead	LT 0.19		LT 0.19	
Manganese	0.004		0.01	
Molybdenum	LT 0.02		LT 0.02	
Nickel	LT 0.03		LT 0.03	
Total Phosphorus	LT 0.25		LT 0.25	
Selenium	LT 0.30		LT 0.30	
Strontium	0.09		0.09	
Total Sulphur	0.91		0.77	
Tin	LT 0.05		LT 0.05	
Zinc	LT 0.02		0.07	
Total Hardness (as CaCO3)	38		18	
Conductivity at 20 deg C (mS/m)	12.9		8.1	
Langelier Index at 20 deg C	-1.9		-2.9	

DSIR CHEMISTRY DIVISION CHRISTCHURCH

SUPPLEMENTARY WATER REPORT

N2131
N2132

Supply : BANKS PENINSULA WATER SOURCES
Sampling location : KB 310 NURSERY SPRING - HOLDING TANK BELOW SPRING
Sampling location : KB 311 WELL MR REX DAVIS
Taken : 4/3/85 Received : 6/3/85 Reported : 21/8/85

Inspector's No. :	KB 310	KB 311
ANALYSIS		
Units g/m3, except pH or unless otherwise stated.		
pH	6.6 **	6.4 **
pH after aeration	7.9	8.3
Acidity to pH 8.3 (as CO2)	21	58
Total Alkalinity to pH4.5 as HCO3	41	108
Alkalinity to pH 8.3 (as CO3)	NIL	NIL
Turbidity (NTU units)	0.48	0.58
Absorbance units (270nm, 1cm cell)	0.002	0.021
Chemical Oxygen Demand (as O)	LT 2	3
Ammoniacal Nitrogen	LT 0.010	0.038
Nitrite Nitrogen	LT 0.001	0.002
Nitrate Nitrogen	0.77	2.9
Soluble Phosphate (as P)	0.11	LT 0.1
Sulphate	4.2	17
Bromide	0.05	0.16
Chloride	19	36
Fluoride	0.09	0.11
Calcium	7.5	20
Magnesium	1.9	9.2
Potassium	LT 0.38	LT 0.38
Sodium	16	32
Total Silica (as SiO2)	32	24
Aluminium	LT 0.25	LT 0.25
Arsenic	~~LT 0.10~~	LT 0.10
Boron	LT 0.01	0.01
Chromium	LT 0.01	LT 0.01
Cobalt	LT 0.03	LT 0.03
Copper	LT 0.03	LT 0.03
Iron	LT 0.10	0.36 *
Lead	LT 0.19	LT 0.19
Manganese	LT 0.001	LT 0.001
Molybdenum	LT 0.02	LT 0.02
Nickel	LT 0.03	LT 0.03
Total Phosphorus	LT 0.25	LT 0.25
Selenium	LT 0.30	LT 0.30
Strontium	0.09	0.24
Total Sulphur	1.4	5.3
Tin	LT 0.05	LT 0.05
Zinc	LT 0.02	0.03
Total Hardness (as CaCO3)	27	88 *
Conductivity at 20 deg C (mS/m)	13.0	30.8
Langelier Index at 20 deg C	-2.5	-1.9

DSIR CHEMISTRY DIVISION CHRISTCHURCH

SUPPLEMENTARY WATER REPORT

N2133
N2134

Supply : BANKS PENINSULA WATER SOURCES
Sampling location : KB 314 COBB HOUSE SPRING
Sampling location : KB 315 CURRY'S SPRING
Taken : 4/3/85 Received : 6/3/85 Reported : 21/8/85

ANALYSIS
Units g/m3, except pH or unless otherwise stated.

Inspector's No. :	KB 314	KB 315
pH	6.4 ##	6.1 ##
pH after aeration	7.7	7.4
Acidity to pH 8.3 (as CO2)	22	15
Total Alkalinity to pH4.5 as HCO3	26	13
Alkalinity to pH 8.3 (as CO3)	NIL	NIL
Turbidity (NTU units)	0.80	1.0
Absorbance units (270nm, 1cm cell)	0.012	0.005
Chemical Oxygen Demand (as O)	LT 2	LT 2
Ammoniacal Nitrogen	LT 0.010	LT 0.010
Nitrite Nitrogen	0.001	0.003
Nitrate Nitrogen	1.1	1.3
Soluble Phosphate (as P)	0.15	LT 0.1
Sulphate	2.4	2.2
Bromide	LT 0.05	0.06
Chloride	16	18
Fluoride	0.07	LT 0.05
Calcium	5.3	3.4
Magnesium	1.1	0.81
Potassium	LT 0.37	LT 0.37
Sodium	12	12
Total Silica (as SiO2)	25	18
Aluminium	LT 0.25	LT 0.25
Arsenic	LT 0.10	LT 0.10
Boron	LT 0.01	LT 0.01
Chromium	LT 0.010	LT 0.010
Cobalt	LT 0.02	LT 0.02
Copper	LT 0.03	LT 0.03
Iron	LT 0.10	0.38 *
Lead	LT 0.19	LT 0.19
Manganese	0.003	LT 0.001
Molybdenum	LT 0.02	LT 0.02
Nickel	LT 0.03	LT 0.03
Total Phosphorus	LT 0.25	LT 0.25
Selenium	LT 0.30	LT 0.30
Strontium	0.03	0.04
Total Sulphur	0.82	0.78
Tin	LT 0.04	LT 0.04
Zinc	0.04	0.03
Total Hardness (as CaCO3)	18	12
Conductivity at 20 deg C (mS/m)	9.9	8.9
Langelier Index at 20 deg C	-3.0	-3.8

DSIR CHEMISTRY DIVISION CHRISTCHURCH

SUPPLEMENTARY WATER REPORT

N2135
N2136

Supply : BANKS PENINSULA WATER SOURCES
Sampling location : KB 316 PIGEON BAY, HILLTOP SPRING
Sampling location : KB 338 PIGEON BAY, STARVATION GULLY- TANK FROM SPRING
Taken : 4/3/85 Received : 6/3/85 Reported : 21/8/85

ANALYSIS
Units g/m3, except pH or unless otherwise stated.

Inspector's No. :	KB 316		KB 338	
pH	7.0	*	6.0	**
pH after aeration	7.6		7.6	
Acidity to pH 8.3 (as CO2)	6		28	
Total Alkalinity to pH4.5 as HCO3	26		23	
Alkalinity to pH 8.3 (as CO3)	NIL		NIL	
Turbidity (NTU units)	1.5	*	0.54	
Absorbance units (270nm, 1cm cell)	0.004		0.005	
Chemical Oxygen Demand (as O)	LT 2		LT 2	
Ammoniacal Nitrogen	LT 0.010		LT 0.010	
Nitrite Nitrogen	0.006		0.002	
Nitrate Nitrogen	1.8		3.4	
Soluble Phosphate (as P)	0.12		LT 0.1	
Sulphate	4.4		4.4	
Bromide	0.06		0.09	
Chloride	20		24	
Fluoride	0.10		0.08	
Calcium	5.9		6.4	
Magnesium	1.6		1.9	
Potassium	LT 0.38		LT 0.38	
Sodium	16		19	
Total Silica (as SiO2)	28		30	
Aluminium	LT 0.25		LT 0.25	
Arsenic	LT 0.10		LT 0.10	
Boron	LT 0.01		LT 0.01	
Chromium	LT 0.01		LT 0.01	
Cobalt	LT 0.03		LT 0.03	
Copper	LT 0.03		LT 0.03	
Iron	LT 0.10		0.16	*
Lead	LT 0.19		LT 0.19	
Manganese	LT 0.001		LT 0.001	
Molybdenum	LT 0.02		LT 0.02	
Nickel	LT 0.03		LT 0.03	
Total Phosphorus	LT 0.25		LT 0.25	
Selenium	LT 0.30		LT 0.30	
Strontium	0.07		0.09	
Total Sulphur	1.6		1.5	
Tin	LT 0.05		LT 0.05	
Zinc	0.04		LT 0.02	
Total Hardness (as CaCO3)	21		24	
Conductivity at 20 deg C (mS/m)	12.1		14.2	
Langelier Index at 20 deg C	-2.4		-3.4	

DSIR CHEMISTRY DIVISION CHRISTCHURCH

WATER REPORT

N2137
N2138

Supply : BANKS PENINSULA WATER SOURCES
Sampling location : KB 339 PIGEON BAY, BULL PADDOCK SPRING
Sampling location : KB 340 PIGEON BAY, TOP GLEN
Taken : 5/3/85 Received : 6/3/85 Reported : 21/8/85

Inspector's No. :	KB 339		KB 340	
ANALYSIS				
Units g/m3, except pH or unless otherwise stated.				
pH	7.3	#	6.8	##
pH after aeration	8.3		7.7	
Acidity to pH 8.3 (as CO2)	20		11	
Total Alkalinity to pH4.5 as HCO3	235		26	
Alkalinity to pH 8.3 (as CO3)	NIL		NIL	
Turbidity (NTU units)	0.42		0.20	
Absorbance units (270nm, 1cm cell)	0.016		0.002	
Chemical Oxygen Demand (as O)	LT 2		LT 2	
Ammoniacal Nitrogen	LT 0.010		LT 0.010	
Nitrite Nitrogen	0.003		LT 0.001	
Nitrate Nitrogen	1.8		0.57	
Soluble Phosphate (as P)	LT 0.1		LT 0.1	
Sulphate	18		3.4	
Bromide	0.27		0.08	
Chloride	61		20	
Fluoride	0.13		0.07	
Calcium	30		5.4	
Magnesium	18		1.5	
Potassium	LT 0.52		LT 0.38	
Sodium	72		13	
Total Silica (as SiO2)	49		22	
Aluminium	LT 0.07		LT 0.25	
Arsenic	LT 0.05		LT 0.10	
Boron	LT 0.01		LT 0.01	
Cadmium	LT 0.009		NA	
Chromium	LT 0.006		LT 0.01	
Cobalt	LT 0.007		LT 0.03	
Copper	LT 0.02		LT 0.03	
Iron	0.08		LT 0.10	
Lead	LT 0.05		LT 0.19	
Manganese	0.008		LT 0.001	
Molybdenum	LT 0.005		LT 0.02	
Nickel	LT 0.02		LT 0.03	
Total Phosphorus	LT 0.07		LT 0.25	
Selenium	LT 0.09		LT 0.30	
Strontium	0.33		0.06	
Total Sulphur	5.6		1.1	
Tin	LT 0.10		LT 0.05	
Zinc	LT 0.07		0.04	
Total Hardness (as CaCO3)	149	*	20	
Conductivity at 20 deg C (mS/m)	53.0		10.8	
Langelier Index at 20 deg C	-0.6		-2.6	

DSIR CHEMISTRY DIVISION CHRISTCHURCH

SUPPLEMENTARY WATER REPORT

N2139

Supply : BANKS PENINSULA WATER SOURCES
Sampling location : KB 341 PIGEON BAY, BOTTOM GLEN SPRING
Taken : 5/3/85 Received : 6/3/85 Reported : 21/8/85

Inspector's No. : KB 341

ANALYSIS
Units g/m3, except pH or unless otherwise stated.

pH	7.4
pH after aeration	8.3
Acidity to pH 8.3 (as CO2)	11
Total Alkalinity to pH4.5 as HCO3	123
Alkalinity to pH 8.3 (as CO3)	NIL
Turbidity (NTU units)	0.50
Absorbance units (270nm, 1cm cell)	0.007
Chemical Oxygen Demand (as O)	LT 2
Ammoniacal Nitrogen	LT 0.010
Nitrite Nitrogen	LT 0.001
Nitrate Nitrogen	4.9
Soluble Phosphate (as P)	0.10
Sulphate	13
Bromide	0.19
Chloride	43
Fluoride	0.14
Calcium	18
Magnesium	8.8
Potassium	LT 0.37
Sodium	49
Total Silica (as SiO2)	40
Aluminium	LT 0.24
Arsenic	LT 0.10
Boron	LT 0.01
Chromium	LT 0.010
Cobalt	LT 0.02
Copper	LT 0.03
Iron	LT 0.10
Lead	LT 0.18
Manganese	LT 0.001
Molybdenum	LT 0.02
Nickel	LT 0.03
Total Phosphorus	0.26
Selenium	LT 0.29
Strontium	0.20
Total Sulphur	4.3
Tin	LT 0.04
Zinc	LT 0.02
Total Hardness (as CaCO3)	81 *
Conductivity at 20 deg C (mS/m)	35.9
Langelier Index at 20 deg C	-0.9

APPENDIX 6

DYE TRACING OF SUBTERRANEAN FLOW PATHS

APPENDIX 6

DYE TRACING OF SUBTERRANEAN FLOWPATHS

A6.1 REFERENCE

DREW, D.P., SMITH, D.I. (1969): Techniques for the tracing of subterranean drainage. Brit. Geomorph. Res. Gp. Tech. Bull. No. 2. pp 3 - 13.

A6.2 THEORY

The tracing of subterranean flow lines is important where the groundwater component of total areal drainage is large. In addition to proving flow lines, the use of a suitable tracing agent makes it possible to assess the rates of flow of underground waters.

In considering dye tracing a distinction should be made between water that disappears underground at a discrete point (eg. stream sink) and water which sinks directly into the soil and surficial cover and thence into the bedrock without first being concentrated into channel flow (percolation). More specialised techniques are required to trace the percolation component of subterranean drainage.

For dye tracing water is distinctively coloured using a dye - stuff visible at low concentrations. Detection may be by direct observation or by absorption of the dye on a suitable surface. The dye - stuffs most commonly used in New Zealand are fluorescein and rhodamine Wt.

A6.3 METHOD

Fluorescein is rapidly absorbed on passage through soil and silt and therefore is unsuitable for tracing percolation water. As a result rhodamine Wt was chosen as the most suitable dye for tracing percolation and groundwater flow in Akaroa County. Automatic detection of dye using treated cotton hanks in selected springs was employed. The procedure is as follows:

1) The dyes. Rhodamine Wt is obtained in 20% solution. Further dilution and injection of the dye in the recharge area was facilitated by the excavation of a 1.5 m hole in mixed colluvium into which the solution was poured. Approximately 100 g of rhodamine Wt per kilometre of underground travel per 0.15 cubic metre/second discharge are required in low absorbancy aquifers (eg. lavas). This may be increased 50 to 60 times where percolation is involved.

2) The detectors. The detectors, one for each resurgence, are cut (24 cm x 10 cm) from white cotton (no other fibre is adequate).

a) Make a solution of tannic acid in distilled water using 0.9 g acid per detector and enough water to cover the detectors. The strips are placed in this solution which should be in a non - metallic container.

b) The solution is heated slowly to 90 degrees Celsius, maintained at this temperature for 60 to 90 minutes, and then allowed to cool slowly.

c) The detectors are removed and squeezed gently.

d) A solution of potassium antimony tartrate is made (0.5 g per detector in warm water) and the strips are immersed in this solution and allowed to stand for 12 - 24 hours at 20 - 25^{o}C.

e) The cotton strips are removed, squeezed, and well washed in cold water.

f) The detectors are dried and are ready for use.

g) The detectors are tied about the middle with nylon cord and placed in the zone of maximum flow at the resurgence.

3) Analysis. Upon removal from a spring a detector giving a positive result may be visibly stained pink. Often the true dye colouring is masked by a dark blue - black staining of the detector due to an insoluble (in water) complex of iron formed with the tannic acid. The iron staining may be removed by washing the used detector in an E.D.T.A. solution.

a) Dissolve 7 g E.D.T.A. in 200 ml hot distilled water.
b) Agitate a detector in the solution for 10 minutes.
c) Wash the detector in distilled water and dry. The dye if present should then be visible.
d) Use a fresh solution of E.D.T.A. for each detector.

A6.3 RESULTS

No positive results were obtained when percolation through surficial cover was included in the tested flow path. It is assumed that this is due to absorption of the dye by silt and clay.

A positive result was obtained when dye was inserted directly into an open - jointed lava known to be an aquifer, and from which a spring exited directly (Section 3.5).

APPENDIX 7

POROSITY TESTING OF VOLCANIC BEDROCK MATERIAL

APPENDIX 7

POROSITY TESTING OF VOLCANIC BEDROCK MATERIALS

A7.1 AIM

The ratio of the volume of void spaces in rock material to the total volume of the material is known as porosity. Typically unweathered volcanic bedrock material possesses very low porosity while weathered volcanic material has high porosity. Porosity testing of volcanic material has been undertaken to determine how this material porosity relates to the water - bearing properties of the appropriate mass in field observations.

A7.2 METHOD

The method used to determine porosity and density of volcanic materials in this study is based on the I.S.R.M. Suggested Methods and uses saturation and buoyancy techniques.

Reference: Brown, E.T. Ed. 1981: Rock characterization testing and monitoring: I.S.R.M. selected methods. Pergamon Press. 211 pp.

A7.3 RESULTS

Results are summarised in Table A7.1 (overleaf).

Sample Type	Volume (m^3)	Dry Weight (g)	Saturated Weight (g)	Density kg/m^3	Volume of Voids (m^3)	Porosity (n)
<u>Lava Material</u>						
Unweathered Aphyric Basalt	10.6×10^{-5}	298.22	300.01	2813.4	0.2×10^{-5}	1.8%
Unweathered Phyric Basalt	8.5×10^{-5}	234.95	236.09	2764.1	0.1×10^{-5}	1.2%
Weathered Phyric Basalt	10.1×10^{-5}	114.76	172.47	1136.2	5.8×10^{-5}	57%
Unweathered Vessicular Basalt	16.7×10^{-5}	281.97	340.93	1689.1	5.8×10^{-5}	35%
Rubbly Lava	10.5×10^{-5}	129.63	186.82	1234.6	5.7×10^{-5}	54%
<u>Phyroclastic Material</u>						
Baked Tuff	5.7×10^{-5}	118.36	140.80	2076.5	2.2×10^{-5}	38.6%
Crystal Tuff	8.1×10^{-5}	180.59	201.79	2229.5	2.1×10^{-5}	26%
Unweathered Scoria	7.0×10^{-5}	154.07	169.23	2201.0	1.5×10^{-5}	21%
Weathered Scoria	8.4×10^{-5}	116.22	178.5	1383.6	6.2×10^{-5}	74%
<u>Intrusive Material</u>						
Trachyte (moderately weathered)	8.9×10^{-5}	186.47	203.09	2095.2	1.7×10^{-5}	19%

<u>Table A7.1</u> Summary table of porosity / density testing results.

APPENDIX 8

IN SITU PERMEABILITY TESTING OF SURFICIAL MATERIALS USING THE ROCKET STANDPIPE PERMEAMETER

A8.1 Reference

A8.2 Aim

A8.3 Working principles

A8.4 Installation

A8.5 Operation

A8.6 Measurements

A8.7 Calculations

A8.8 Results

APPENDIX 8

IN SITU PERMEABILITY TESTING OF SURFICIAL MATERIALS USING THE ROCKET STANDPIPE PERMEAMETER

A8.1 REFERENCE

MINISTRY OF WORKS 1972: Standpipe field permeability test. M.O.W. Technical Instruction 21.

A8.2 AIM

In situ permeability testing of surficial materials has been undertaken with the aim of determining relative suitability as infiltration and confining media.

A8.3 WORKING PRINCIPLES

The rocket permeameter is designed as a constant head device for use in soils of low to medium permeability (K less than or equal to 10^{-6} m/sec.). It consists of a 0.94 m high standpipe open at both ends, with a cylindrical reservoir tank connected to the standpipe in such a way that a constant head is maintained in the standpipe at all times (Fig. A8.1).

Atmospheric pressure is maintained in the tank at the air bleed pipe outlet. Thus the effective head in the supply system is equal to the distance X in Fig. A8.1. This pressure from the supply system will equalised by the head Y. The water level in the standpipe is maintained at the level of the air bleed pipe outlet. Water flowing from the bottom of the standpipe into the ground will be replaced by water from the supply tank, the negative (suction) pressure resulting in the top of the sealed tank being relieved by air bubbles from the air bleed pipe.

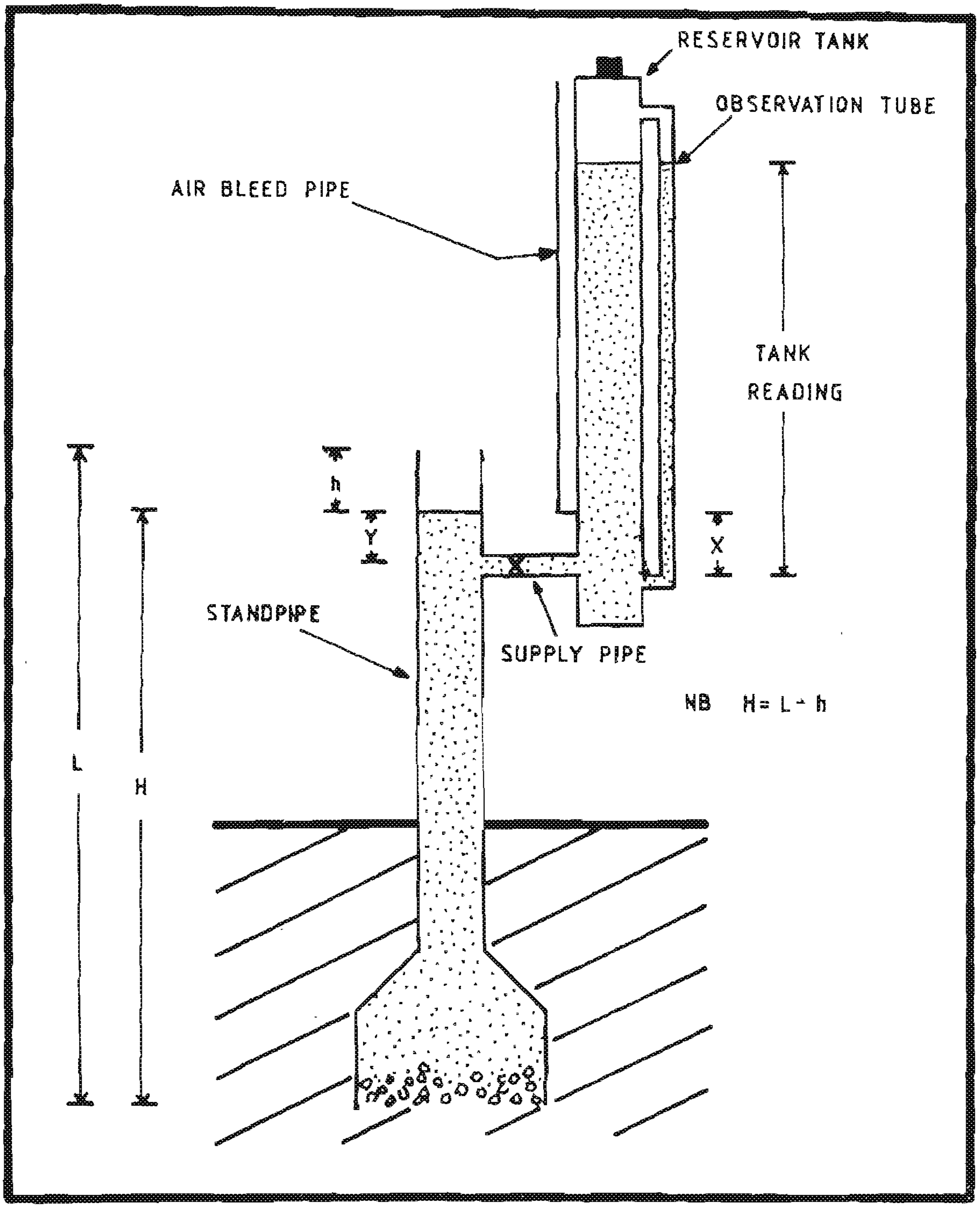

Fig. A8.1 The Rocket Permeameter.

A8.4 INSTALLATION

The installation of the standpipe is adequately covered in Appendix C of the Pukaki Earth Dam Specification H.D. 897. Particular note should be taken of the sections relating to seal dimensions and minimum depth of embedment.

A8.5 OPERATION

Initial soaking of the ground can be accomplished by filling the standpipe and leaving it for at least 24 hours.

After soaking, the supply tank should be filled and sealed. This seal is important. The standpipe should be filled to just below the level of the air bleed pipe outlet. Then open the valve on the supply pipe and ensure the air bubbles are eliminated from the system. No measurements should be made until the tank level begins to drop. The standpipe water level will need to drop to the level of the air bleed pipe outlet and water drain from the air bleed pipe before this occurs.

If, during the duration of the test, the tank water level drops to near the bottom of the observation tube, refilling of the tank will be required. This can be accomplished by firstly closing the supply pipe valve and then removing the top cap and adding water. Reseal the cap, open the valve and again wait until the tank water level starts to drop before taking further readings.

On no account should any water be added to the standpipe at any time. The standpipe should also be protected from rainwater entry and evaporation.

A8.6 MEASUREMENTS

After installing the standpipe and before covering the base with gravel the distance from the ground level inside the standpipe to the top lip of the standpipe must be measured. This reading is recorded as L (0.94 m for standpipe used).

Once the permeameter has commenced to run, measurements should be made at fixed time intervals, the length of these intervals depending on the rate of drop of the tank water level. Readings should be made at least every 12 hours.

The two measurements which must be made at every time interval are:

a) Head reading: measure down from the top lip of the standpipe to the water surface (h). Subtract this measurement from the above reading L (0.94 m) to give the head reading, H. Record in appropriate column.

b) Tank reading: measure from fixed reference point at the bottom of the tank observation tube to the water meniscus in the tube. Record in appropriate column.

Also record the date, time, and elapsed time since the last reading was made.

A8.7 CALCULATIONS

Calculate K (permeability) using the following procedure:

1) Calculate the average head over the time period (the two readings should not vary more than a cm or two. If they do, then either a reading error has been made or the permeameter is not functioning correctly).

2) Calculate H/R (R is standpipe radius). Obtain c_1/Pi from graph (Fig. A8.2) and hence calculate c_1.

3) Calculate tank level difference over time period.

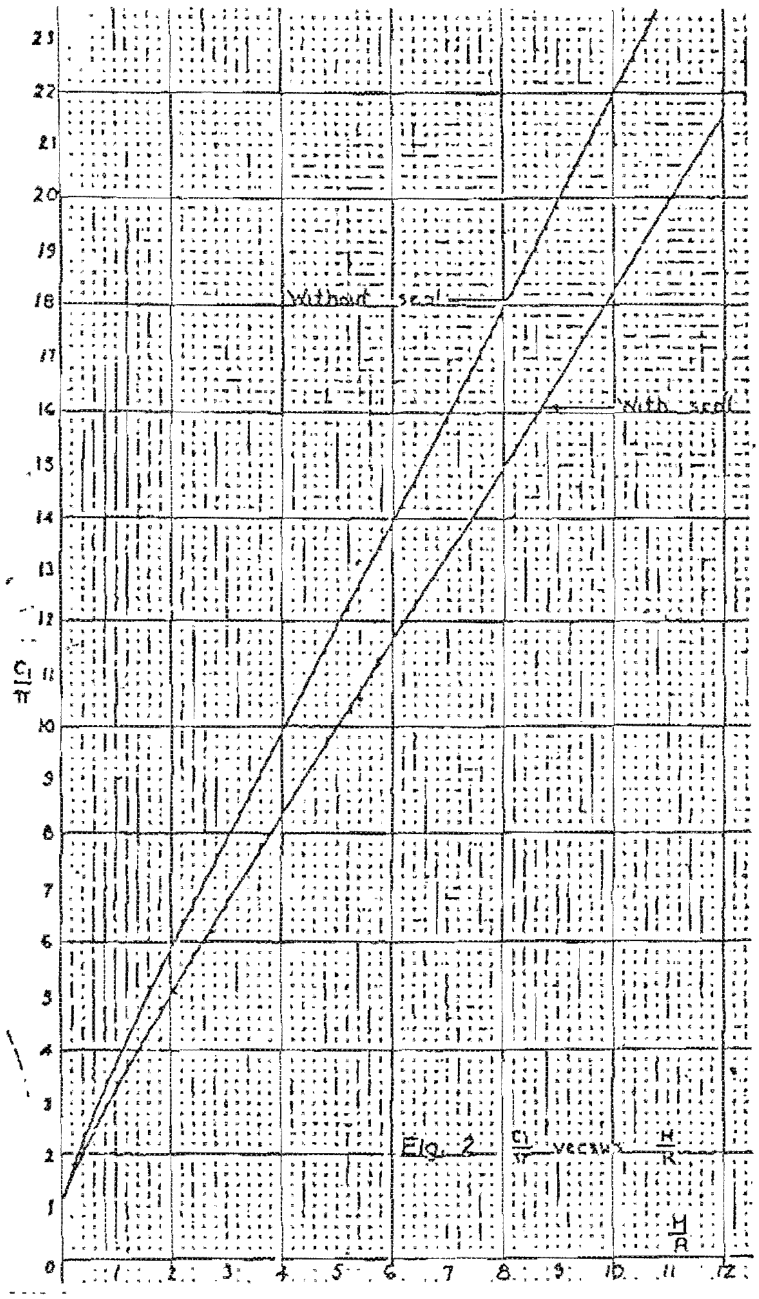

Fig. A8.2 Graph used to determine c_1/pi from H/R.

4) Calculate tank discharge Q, ie

$$Q = F \times \text{tank diff./Time in hours}$$

5) Calculate K.

$$K = Q/(c_1 R^2 \times 3600) \text{ m/sec.}$$

For the permeameter used in this study calculations were made on the enclosed results sheets.

A8.8 RESULTS

Six in situ permeability tests were performed in Akaroa County in loess, mixed colluvium, and volcanic colluvium situations. Results of these tests are presented over the next six pages.

SOILS & FOUNDATIONS (1973) LTD
FIELD PERMEABILITY TEST
ROCKET STANDPIPE PERMEAMETER

TEST NO Airfall loess
TESTED RAS
CALCULATED RAS
CHECKED

PERM NO
TANK NO
LOCATION WAINUI

NOTES :

DATE	TIME	ELAPSED TIME(hrs	HEAD (h) READING m	HEAD (0.940-h)	$\frac{H}{R}$	$\frac{Cl}{\pi}$	TANK READING m	TANK DROP m	PERMEABILITY (K m/sec)
	0		.14	.80			.85		
		0.5			5.3	10.4		.12	3.5×10^{-7}
	0.5		.14	.80			.73		
		0.5			5.3	10.4		.11	3.2×10^{-7}
	1.0		.14	.80			.62		
		0.5			5.3	10.4		.115	3.3×10^{-7}
	1.5		.14	.80			.51		
		1.0			5.3	10.4		.215	3.1×10^{-7}
	2.5		.14	.80			.29		

$$K = \frac{1.5 \times 10^{-5} \times \text{TANK DROP}}{\text{TIME (hrs)} \times \frac{Cl}{\pi}}$$

1. STANDPIPE LENGTH = 0.940 m
2. STANDPIPE RADIUS = 0.150 m
3. $\frac{Cl}{\pi}$ from graph

SOILS & FOUNDATIONS (1973) LTD
FIELD PERMEABILITY TEST
ROCKET STANDPIPE PERMEAMETER

TEST NO Recently slumped loess
TESTED
CALCULATED RAS
CHECKED

PERM NO
TANK NO
LOCATION WAINUI

DATE	TIME	ELAPSED TIME(hrs)	HEAD (h) READING m	HEAD (0.940-h)	$\frac{H}{R}$	$\frac{Cl}{\pi}$	TANK READING m	TANK DROP m	PERMEABILITY (K m/sec)
	0		.13	.81			.80		
		0.25			5.4	10.6		.225	1.27×10^{-6}
	0.25		.13	.81			.58		
		0.25			5.4	10.6		.225	1.27×10^{-6}
	0.5		.13	.81			.35		
		0.25			5.4	10.6		.25	1.4×10^{-6}
	0.75		.13	.81			.10		

NOTES :

$$K = \frac{1.5 \times 10^{-5} \times \text{TANK DROP}}{\text{TIME (hrs)} \times \frac{Cl}{\pi}}$$

1. STANDPIPE LENGTH = 0.940 m
2. STANDPIPE RADIUS = 0.150 m
3. $\frac{Cl}{\pi}$ from graph

SOILS & FOUNDATIONS (1973) LTD
FIELD PERMEABILITY TEST
ROCKET STANDPIPE PERMEAMETER

TEST NO Mixed colluvium
TESTED (10% volcanics)
CALCULATED RAS
CHECKED

PERM NO
TANK NO
LOCATION FRENCH HILL
NOTES :

DATE	TIME	ELAPSED TIME(hrs	HEAD (h) READING m	HEAD (0.940-h)	$\frac{H}{R}$	$\frac{C1}{\pi}$	TANK READING m	TANK DROP m	PERMEABILITY(K m/sec)
	0		.14	.80			.86		
		0.5			5.3	10.4		.055	1.59×10^{-7}
	0.5		.15	.79			.805		
		0.5			5.3	10.4		.055	1.59×10^{-7}
	1.0		.14	.80			.75		
		0.5			5.3	10.4		.055	1.59×10^{-7}
	1.5		.14	.80			.695		
		0.5			5.3	10.4		.055	1.59×10^{-7}
	2.0		.14	.80			.64		

$$K = \frac{1.5 \times 10^{-5} \times \text{TANK DROP}}{\text{TIME (hrs)} \times \frac{C1}{\pi}}$$

1. STANDPIPE LENGTH = 0.940 m
2. STANDPIPE RADIUS = 0.150 m
3. $\frac{C1}{\pi}$ from graph

SOILS & FOUNDATIONS (1973) LTD
FIELD PERMEABILITY TEST
ROCKET STANDPIPE PERMEAMETER

TEST NO Mixed colluvium (25% volcanics)
TESTED
CALCULATED RAS
CHECKED

PERM NO
TANK NO
LOCATION FRENCH HILL

DATE	TIME	ELAPSED TIME(hrs)	HEAD (h) READING m	HEAD (0.940-h)	$\frac{H}{R}$	$\frac{Cl}{\pi}$	TANK READING m	TANK DROP m	PERMEABILITY (K m/sec)
	0		.14	.80			.79		
		1			5.3	10.4		.355	5.1×10^{-7}
	1		.14	.80			.435		
		1			5.3	10.4		.345	5.0×10^{-7}
	2		.14	.80			.09		
		1			5.3	10.4		.33(refilled to .85m)	
	3		.14	.80			.52		4.8×10^{-7}

NOTES :

$$K = \frac{1.5 \times 10^{-5} \times \text{TANK DROP}}{\text{TIME (hrs)} \times \frac{Cl}{\pi}}$$

1. STANDPIPE LENGTH = 0.940 m
2. STANDPIPE RADIUS = 0.150 m
3. $\frac{Cl}{\pi}$ from graph

SOILS & FOUNDATIONS (1973) LTD
FIELD PERMEABILITY TEST
ROCKET STANDPIPE PERMEAMETER

TEST NO Mixed colluvium
TESTED (35% volcanics)
CALCULATED RAS
CHECKED

PERM NO
TANK NO
LOCATION FRENCH HILL
NOTES :

DATE	TIME	ELAPSED TIME(hrs	HEAD (h) READING m	HEAD (0.940-h)	$\frac{H}{R}$	$\frac{C1}{\pi}$	TANK READING m	TANK DROP m	PERMEABILITY (K m/sec)
	0		.15	.79					
		.17			5.3	10.4		.28	2.4×10^{-6}
	.17.		.15	.79					
		.08			5.3	10.4		.15	2.6×10^{-6}
	.25		.15	.79					
		.08			5.3	10.4		.15	2.6×10^{-6}
	.33		.15	.79					
		.08			5.3	10.4		.15	2.6×10^{-6}
				REFILL					
	.58		.15	.79					
		.08			5.3	10.4		.15	2.6×10^{-6}
	.67		.15	.79					

$$K = \frac{1.5 \times 10^{-5} \times \text{TANK DROP}}{\text{TIME (hrs)} \times \frac{C1}{\pi}}$$

1. STANDPIPE LENGTH = 0.940 m
2. STANDPIPE RADIUS = 0.150 m
3. $\frac{C1}{\pi}$ from graph

SOILS & FOUNDATIONS (1973) LTD

FIELD PERMEABILITY TEST

ROCKET STANDPIPE PERMEAMETER

TEST NO Volcanic colluvium

TESTED RAS

CALCULATED

CHECKED

PERM NO

TANK NO

LOCATION Pigeon Bay

NOTES :

DATE	TIME	ELAPSED TIME(hrs)	HEAD (h) READING m	HEAD (0.940-h)	$\frac{H}{R}$	$\frac{Cl}{\pi}$	TANK READING m	TANK DROP m	PERMEABILITY (K m/sec)
	0		.18	.76			.85		
		.017			5.0	10		.11	9.7×10^{-6}
	.017		.21	.73			.74		
		.017			4.8	9.7		.12	1.1×10^{-5}
	.034		.22	.72			.62		
		.017			4.7	9.5		.11	1.0×10^{-5}
	.051		.24	.70			.51		
		.017			4.7	9.4		.12	1.1×10^{-5}
	.068		.24	.70			.39		
		.017			4.6	9.3		.12	1.1×10^{-5}
	.085		.25	.69			.27		

$$K = \frac{1.5 \times 10^{-5} \times \text{TANK DROP}}{\text{TIME (hrs)} \times \frac{Cl}{\pi}}$$

1. STANDPIPE LENGTH = 0.940 m
2. STANDPIPE RADIUS = 0.150 m
3. $\frac{Cl}{\pi}$ from graph

APPENDIX 9

DISCHARGE MONITORING OF SPRINGS

APPENDIX 9

DISCHARGE MONITORING OF SPRINGS

A9.1 METHOD

Discharge monitoring of springs has been undertaken on two scales:

1) Monthly monitoring of 19 springs to determine annual flow fluctuation. A single reading taken at the end of each month is assumed to be representative of the discharge rate for that month. This was performed between September, 1984, and August, 1985.

2) Daily monitoring of the Abbatoir #1 Spring in combination with daily rainfall monitoring to determine minor fluctuations, eg. response to storm events.

Criteria used for selection of springs to be monitored monthly include:

a) Management interest, eg. possible future utilisation of the spring.
b) Springs should show a variety of geographic position, immediate lithologic source, and size.
c) Springwater should be easily confined for measurement purposes.
d) Other factors, eg. good geologic exposure, road access.

Two methods have been utilised in determining spring discharge:

1) Timed filling of a known volume (a calibrated 10

A9.1

litre bucket) for flows normally less than 35 litres per minute.

2) Three V - notch weirs were installed to determine discharge of higher flow springs, ie. Abbatoir #1, Abbatoir #2, and the Cob House springs.

A Foxboro water level recorder was installed to record fluctuations in flow of the Abbatoir #1 Spring, but was unsuccessful because of the small magnitude of fluctuation behind the V - notch weir ($<$ 100 mm).

A9.2 SPRING FLOW USING V - NOTCH WEIRS

Determination of flow using V - notch weirs is governed by British Standards:

BS 3680: Part 4A: 1981.

Fig. A9.1 shows the typical 90 degree V - notch weir as used in Akaroa County. These were sealed into the appropriate stream channel using a cement/premix gravel slurry or bentonite pellets to stop leakage.

The Kindsvater - Shen formula for triangular V - notch weirs is used to determine discharge from data collected, ie

$$Q = C_d \times 8/15 \times \tan\theta/2 \times (2g)^{0.5} \times h^{2.5}$$

where Q is discharge,

C_d is the coefficient of discharge determined by field calibration,

is the angle of the V in degrees, and

h is the effective head measured from the base of the V.

Because of the relatively low maximum flows expected (less than 900 litres per minute) the depth of V utilised in

Akaroa County is only 200 mm, and the weirs are constructed of 3 mm galvanised steel.

A9.3 STREAM FLOW MEASUREMENT

Stream flow beneath State Highway 75 (Grid Ref. N36 984166) below, and draining, the Abbatoir springs has been crudely determined by measurement of rate of movement of a small object (eg. ping - pong ball) through the culvert and maximum depth of flow in this culvert. Flow is subsequently calculated using the equation:

$$Q = V/t$$

where V is the volume of the water body contained in the culvert and t is the time taken for the object to travel through the culvert.

$$V = A \times l$$

where A is the cross - sectional area of the water body determined from Table A9.1 (overleaf) and l is the length of the culvert.

A9.4 RESULTS

Results from spring discharge monitoring and stream flow under State Highway 75 are presented in the following tables overleaf:

Monthly spring discharge monitoring: Table A9.2

Stream flow monitoring (N36 984166): Table A9.2

Daily spring discharge - Abbatoir
Spring #1 : Table A9.3

Table [illegible] Circles: Areas of Segments*

[illegible]

Table A9.1 Table used to determine cross sectional area of water in a culvert.

Spring	Sept. (1984)	Oct.	Nov.	Dec.	Jan. (1985)	Feb.	Mar.	April	May	June	July	Aug.
Akaroa												
Yards Sp	2.8	2.2	1.8	1.2	1.0	0.1	0.2	0.4	0.5	0.4	7.4	3.0
Cob House Sp	260	155	134	106	64	74	57	56	57	74	846	217
Curry's Sp	10.0	7.0	5.5	5.0	2.9	2.6	2.3	1.9	2.2	2.5	31.5	14.0
Purple Pk Sp	6.3	2.4	2.9	0.7	0.1	0.0	0.0	0.0	0.0	0.0	19.0	5.6
Pigeon Bay												
Starvation Gully 1	3.7	2.8	2.1	1.8	0.8	0.7	0.5	0.4	0.2	0.1	5.6	2.9
2	6.4	5.0	4.6	3.7	2.8	2.5	2.3	2.0	1.8	1.6	14.0	6.6
3	4.7	4.2	3.8	3.5	2.8	2.7	2.6	2.4	2.3	2.0	7.3	5.1
Bottom Glen Sp	22.8	20.0	18.4	15.6	12.9	12.2	11.4	10.8	11.6	9.8	9.7	8.5
Top Glen Sp	21.6	18.0	15.3	14.1	10.4	10.2	9.8	7.1	6.3	4.8	12.8	19.2
Cemetery Sp	21.0	14.1	11.1	8.4	7.2	8.0	8.4	8.0	7.9	8.7	10.0	8.5
Top Pigeon Bay Sp	18.8	13.2	6.2	4.8	2.4	2.4	1.2	1.1	1.1	0.7	3.4	2.6
Old Summit Rd Sp	10.7	4.7	2.2	1.1	0.2	0.0	0.0	0.0	0.0	0.0	3.2	3.5
French Farm												
Abattoir 1 Sp	209	102	55	35	21	25	20	18	31	39	506	265
Abottoir 2 Sp	187	107	66	49	43	42	35	33	42	54	279	242
Main Road Ck	-	996	540	343	289	304	239	229	364	470	3000	
Lower Loess Sp	0.75	0	0	0	0	0	0	0	0	0.0	0.1	0.1
Nursery Sp	40.2	29.4	24.4	19.2	13.6	11.0	9.5	7.3	9.6	7.7	34.4	30.3
Saddle Hill Sp	4.8	4.3	1.2	0.6	0.2	0.0	0.0	0.0	0.1	0.0	12.0	5.4
Otehore Sp	66.0	37.5	48.0	22.8	18.0	-	20.4	18.0	22.2	16.8	24	21

Table A9.2 Summary table of spring discharge monitoring in Akaroa County as measured between September, 1984 and August, 1985. (litres/min)

June		July			
Day	Discharge (l/min.)	Day	Discharge (l/min.)	Day	Discharge (l/min.)
9	31	1	43	22	157
10	29	2	43	23	207
11	29	3	43	24	234
12	27	4	41	25	227
13	22	5	44	26	220
14	22	6	41	27	213
15	24	7	40	28	234
16	24	8	40	29	842
17	25	9	39	30	857
18	25	10	40	31	702
19	27	11	38		
20	25	12	38		
21	25	13	-		
22	27	14	-		
23	-	15	-		
24	-	16	120		
25	-	17	134		
26	36	18	134		
27	38	19	129		
28	40	20	-		
29	40	21	-		
30	40				

Table A9.3 Daily spring discharge data as recorded at the Abattoir No. 1 Spring over a six week period in June and July, 1985.

APPENDIX 10

STREAM FLOW DATA

APPENDIX 10

STREAM FLOW DATA

Stream gaugings determined by the North Canterbury Catchment Board for Akaroa County are summarised in the following six pages.

SELECTION FACTOR :- TIKAO BAY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
2403	TIKAO BAY STREAM	BEACH	S94:237235	750715	0.000	0.0130	0.052	0.250	8.0
4706	TIKAO BAY STREAM	BEACH	S94:247235	830614	0.000	0.0260	0.112	0.236	0.0
4717	TIKAO BAY STREAM	BEACH	S94:237235	830629	0.000	0.0130	0.055	0.247	0.0

SELECTION FACTOR :- FRENCH FARM STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
3224	FRENCH FARM ~~BAY STM~~ Stream	VALLEY ROAD BRIDGE	S94:238258	780405	0.000	0.0200	0.109	0.183	0.0
4709	FRENCH FARM STREAM	WAINUI ROAD	S94:239256	830614	0.000	0.3600	0.957	0.376	0.0
4716	FRENCH FARM STREAM	WAINUI ROAD	S94:239256	830629	0.000	0.2030	1.080	0.188	0.0
4757	FRENCH FARM STREAM	WAINUI ROAD	S94:239256	830811	0.000	0.1490	0.924	0.156	0.0

SELECTION FACTOR :- WAINUI STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
2081	WAINUI STREAM	BELOW YMCA CAMP	S94:227217	750303	0.000	0.0910	0.216	0.421	13.0
2191	WAINUI STREAM	BELOW YMCA CAMP	S94:227217	750505	0.000	0.0900	0.204	0.441	8.0
2404	WAINUI STREAM	BELOW YMCA CAMP	S94:227217	750715	0.000	0.2390	0.599	0.399	8.0
3223	WAINUI STREAM	BELOW YMCA CAMP	S94:227217	780405	0.000	0.0320	0.232	0.138	0.0
4708	WAINUI STREAM	WAINUI ROAD	S94:235212	830614	0.000	0.4460	1.015	0.440	0.0
4718	WAINUI STREAM	WAINUI ROAD	S94:235212	830629	0.000	0.2530	0.611	0.414	0.0
5576	WAINUI STM	WAINUI ~~MAIN~~ RD-~~BOE 1~~	S94:234213	850114	0.000	0.0330	0.190	0.172	0.0
5577	~~WAINUI STM~~ (No 2)	WAINUI ~~MAIN~~ RD-~~BOE 2~~	S94:234204	850114	0.000	0.0220	0.181	0.121	0.0
5578	WAINUI STM (NO 2)	JUBILEE RD	S94:227199	850114	0.000	0.0230	0.108	0.217	0.0

SELECTION FACTOR :- JUBILEE ROAD STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
2080	JUBILEE ROAD STREAM	WAINUI	S94:234204	750303	0.000	0.0530	0.110	0.482	12.5
2192	JUBILEE ROAD STREAM	WAINUI	S94:234204	750505	0.000	0.0350	0.337	0.104	9.0
2405	JUBILEE ROAD STREAM	WAINUI	S94:234204	750715	0.000	0.0980	0.227	0.432	8.5
4707	JUBILEE ROAD STREAM	WAINUI	S94:234204	830614	0.000	0.2360	0.821	0.287	0.0
4719	JUBILEE ROAD STREAM	WAINUI	S94:234204	830629	0.000	0.1200	0.222	0.539	0.0

SELECTION FACTOR :- RUE BALGUERIE STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
2097	RUE BALGUERIE STREAM	PURPLE PEAKS ROAD	S94:301218	750303	0.000	0.0140	0.076	0.184	14.0
2159	RUE BALGUERIE STREAM	AKAROA	S94:297221	750505	0.000	0.0340	0.485	0.070	10.0
2413	RUE BALGUERIE STREAM	AKAROA	S94:297221	750715	0.000	0.1170	1.310	0.090	9.0
4546	RUE BALGUERIE STREAM	AKAROA	S94:297221	830111	0.000	0.0110	0.097	0.110	0.0
4597	RUE BALGUERIE STREAM	AKAROA	S94:297221	830317	0.000	0.0170	0.050	0.341	0.0
4619	RUE BALGUERIE STREAM	AKAROA	S94:297221	830323	0.000	0.0020	0.018	0.126	0.0
4653	RUE BALGUERIE STREAM	AKAROA	S94:297221	830411	0.000	0.0040	0.025	0.156	0.0
4702	RUE BALGUERIE STREAM	AKAROA	S94:297221	830614	0.000	0.2580	0.539	0.478	0.0
4726	RUE BALGUERIE STREAM	AKAROA	S94:297221	830629	0.000	0.1130	0.410	0.277	0.0
4793	RUE BALGUERIE STREAM	AKAROA	S94:297221	830810	0.000	0.0780	0.347	0.225	0.0
4821	RUE BALGUERIE STREAM	AKAROA	S94:297221	831012	0.000	0.1100	0.370	0.300	0.0
4879	RUE BALGUERIE STREAM	AKAROA	S94:279221	831102	0.000	0.1240	0.368	0.335	0.0
5350	RUE BALGUERIE	AKAROA	S94:297221	840802	0.000	0.0730	0.358	0.206	0.0
5409	RUE BALGUERIE STREAM	AKAROA	S94:297221	840829	0.000	0.0540	0.329	0.163	0.0

SELECTION FACTOR :- AYLMERS STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
5352	AYLMERS STREAM	AKAROA	S94:285218	840802	0.000	0.0640	0.676	0.094	0.0
5410	AYLMERS STREAM	AKAROA	S94:285218	840829	0.000	0.0430	0.258	0.167	0.0

SELECTION FACTOR :- WOODHILLS RD STM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
4700	WOODHILLS ROAD STM	AKAROA	S94:293229	830614	0.000	0.1050	0.306	0.342	0.0
4724	WOODHILLS RD STM	AKAROA	S94:293229	830629	0.000	0.0490	0.246	0.199	0.0
5411	WOODHILLS RD STM	AKAROA	S94:293229	840829	0.000	0.0290	0.096	0.299	0.0

SELECTION FACTOR :- RUE GREHAN STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
4596	RUE GREHAN STREAM	TENNIS COURTS	S94:293228	830317	0.000	0.0040	0.036	0.117	0.0
4701	RUE GREHAN STREAM	TENNIS COURTS	S94:293228	830614	0.000	0.1670	0.719	0.232	0.0
4725	RUE GREHAN STREAM	TENNIS COURTS	S94:293228	830629	0.000	0.0690	0.577	0.120	0.0

SELECTION FACTOR :- KAIK STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
4704	KAIK STREAM	AKAROA	S94:272188	830614	0.000	0.1270	1.100	0.116	0.0
4728	KAIK STREAM	AKAROA	S94:272188	830629	0.000	0.0680	0.710	0.096	0.0

.ECTION FACTOR :- LITTLE AKALOA STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP	COMMENT
288	LITTLE AKALOA STREAM	BAY	S84:316302	700908	0.000	0.1570	0.899	0.174	0.0	
4149	LITTLE AKALOA STREAM	BAY	S84:316382	820211	0.000	0.0384	0.119	0.321	0.0	
4150	LITTLE AKALOA RD DRN	BAY	S84:314381	820211	0.000	0.0005	0.003	0.151	0.0	
4583	LITTLE AKALOA STREAM	BAY	S84:316382	830309	0.000	0.0370	0.175	0.214	0.0	
5346	LITTLE AKALOA STREAM	BAY	S84:315382	840802	0.000	0.2130	0.989	0.216	0.0	
5400	LITTLE AKALOA STREAM	BAY	S84:315382	840829	0.000	0.1590	0.817	0.195	0.0	

.ECTION FACTOR :- PIGEON BAY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP	COMMENT
4622	PIGEON BAY STREAM	PIGEON BAY	S84:230347	830323	0.000	0.0410	0.186	0.221	0.0	
4682	PIGEON BAY STREAM	PIGEON BAY	S84:230367	830517	0.000	0.2270	0.000	0.000	0.0	
4762	PIGEON BAY STREAM	PIGEON BAY	S84:230367	830811	0.000	0.3020	0.772	0.391	0.0	
4881	PIGEON BAY STM	PIGEON BAY	S84:230367	831103	0.000	0.2970	0.918	0.324	0.0	
5341	PIGEON BAY STREAM	PIGEON BAY	S84:230367	840801	0.000	0.3960	0.938	0.422	0.0	
5399	PIGEON BAY STREAM	PIGEON BAY	S84:230367	840829	0.000	0.2160	0.697	0.309	0.0	

.ECTION FACTOR :- HOLMES BAY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP	COMMENT
1129	HOLMES BAY STREAM	TOP TRIBUTARY	S84:199352	731002	0.000	0.0170	0.087	0.195	11.0	
1130	HOLMES BAY STREAM	ABOVE TOP TRIB	S84:200353	731002	0.000	0.0310	0.197	0.157	11.0	
1131	HOLMES BAY STREAM	2ND TRIBUTARY	S84:200355	731002	0.000	0.0060	0.052	0.115	11.0	
1132	HOLMES BAY STREAM	TOP BRIDGE	S84:206369	731002	0.000	0.0620	0.282	0.219	11.0	
1133	HOLMES BAY STREAM	BOTTOM BRIDGE	S84:207374	731002	0.000	0.0780	0.248	0.315	11.0	
1134	HOLMES BAY STREAM	3RD TRIBUTARY	S84:205372	731002	0.000	0.0060	0.077	0.078	11.0	
1135	HOLMES BAY STREAM	4TH TRIBUTARY	S84:207375	731002	0.000	0.0020	0.018	0.082	11.0	
4549	HOLMES BAY STREAM	HOLMES BAY	S84:214382	830111	0.000	0.0280	0.000	0.000	0.0	SEE CARD
4623	HOLMES BAY STREAM	HOLMES BAY	S84:214382	830323	0.000	0.0190	0.150	0.129	0.0	
4683	HOLMES BAY STREAM	HOLMES BAY	S84:214382	830517	0.000	0.1080	0.318	0.340	0.0	
4763	HOLMES BAY STREAM	HOLMES BAY	S84:214383	830811	0.000	0.1340	0.628	0.214	0.0	
4827	HOLMES BAY STREAM	HOLMES BAY	S84:214383	831013	0.000	0.1350	0.578	0.234	0.0	
4882	HOLMES BAY STREAM	HOLMES BAY	S84:214383	831103	0.000	0.1760	0.635	0.277	0.0	
5340	HOLMES BAY STREAM	HOLMES BAY	S84:214382	840801	0.000	0.1870	0.291	0.000	0.0	2 CHANNELS
5398	HOLMES BAY STREAM	HOLMES BAY	S84:214382	840829	0.000	0.1080	0.510	0.212	0.0	

ELECTION FACTOR :- STARVATION GULLY STM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP	COMMENT
2090	STARVATION GULLY STR	PIGEON BAY	S84:234366	750303	0.000	0.0140	0.120	0.117	13.5	
2196	STARVATION GULLY STM	PIGEON BAY	S84:234366	750505	0.000	0.0030	0.101	0.030	10.0	
2410	STARVATION GULLY STM	PIGEON BAY	S84:234366	750715	0.000	0.0250	0.106	0.236	8.0	

SELECTION FACTOR :- ROBINSONS BAY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
4050	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	810820	0.000	0.1950	0.876	0.223	0.0
4101	ROBINSONS BAY STM	AKAROA ROAD	94:288274	811111	0.000	0.0550	0.610	0.090	0.0
4544	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830111	0.000	0.0140	0.180	0.117	0.0
4603	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830317	0.000	0.0210	0.072	0.288	0.0
4617	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830323	0.000	0.0110	0.079	0.139	0.0
4651	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830414	0.000	0.0150	0.100	0.151	0.0
4676	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830517	0.000	0.0220	0.128	0.176	0.0
4698	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830614	0.000	0.3340	1.100	0.303	0.0
4722	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830629	0.000	0.1540	0.788	0.195	0.0
4751	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	830810	0.000	0.1100	0.694	0.159	0.0
4818	ROBINSONS BAY STM	AKAROA ROAD	S94:288274	831012	0.000	0.1450	0.679	0.214	0.0
4877	ROBINSONS BAY STREAM	AKAROA ROAD	S94:288274	831102	0.000	0.1280	0.778	0.164	0.0
5345	ROBINSONS BAY STREAM	AKAROA ROAD	S94:288274	840801	0.000	0.1500	0.512	0.294	0.0
5407	ROBINSONS BAY STM	AKAROA RD	S94:288274	840829	0.000	0.1060	1.310	0.081	0.0

SELECTION FACTOR :- TAKAMATUA STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
4047	TAKAMATUA CREEK	THE CROFT	S94:310242	810820	0.000	0.1300	0.643	0.202	0.0
4048	TAKAMATUA CREEK	LE BONS TRACK	S94:305247	810820	0.000	0.0810	0.323	0.251	0.0
4049	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	810820	0.000	0.2340	1.030	0.227	0.0
4102	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	811111	0.000	0.0720	0.360	0.200	0.0
4541	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830111	0.000	0.0230	0.253	0.094	0.0
4599	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830317	0.000	0.0210	0.294	0.071	0.0
4618	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830323	0.000	0.0140	0.103	0.131	0.0
4652	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830414	0.000	0.0170	0.143	0.121	0.0
4677	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830517	0.000	0.0440	0.353	0.126	0.0
4699	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830614	0.000	0.4840	1.360	0.356	0.0
4723	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830629	0.000	0.2460	1.160	0.212	0.0
4752	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	830810	0.000	0.1870	1.040	0.179	0.0
4815	TAKAMATUA CREEK	AKAROA ROAD	S94:294252	831017	0.000	0.2250	1.630	0.138	0.0
4878	TAKAMATUA STREAM	AKAROA ROAD	S94:294252	831102	0.000	0.1800	1.060	0.169	0.0
5351	TAKAMATUA STREAM	AKAROA ROAD	S94:294252	840802	0.000	0.1590	0.557	0.286	0.0
5408	TAKAMATUA STREAM	AKAROA ROAD	S94:294252	840829	0.000	0.1290	0.345	0.374	0.0

SELECTION FACTOR :- PAWSONS VALLEY STREA

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
394	PAWSONS VALLEY STM	GOLF CLUB	S94:260295	710112	0.000	0.1790	0.166	0.108	15.0
788	PAWSONS VALLEY STM	GOLF CLUB	S94:262302	721005	0.000	0.0230	0.343	0.070	15.0
789	PAWSONS VALLEY STM	GOLF CLUB	S94:260295	721005	0.000	0.0154	0.106	0.140	12.0
3225	PAWSONS VALLEY STRM	GOLF CLUB	S94:260295	780405	0.000	0.0110	0.059	0.186	0.0
4543	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830111	0.000	0.0060	0.129	0.045	0.0
4601	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830317	0.000	0.0110	0.063	0.180	0.0
4615	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830323	0.000	0.0070	0.075	0.095	0.0
4649	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830414	0.000	0.0100	0.153	0.068	0.0
4674	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830517	0.000	0.0260	0.244	0.105	0.0
4696	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830614	0.000	0.1970	1.200	0.164	0.0
4720	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	830629	0.000	0.0970	0.986	0.098	0.0
4756	PAWSONS VALLEY STM	AKAROA ROAD	S94:262290	830811	0.000	0.0670	0.699	0.095	0.0
4831	PAWSONS VALLEY STM	AKAROA ROAD	S94:262290	831013	0.000	0.0410	0.124	0.336	0.0
4889	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	831103	0.000	0.0790	0.446	0.178	0.0
5405	PAWSONS VALLEY STREA	AKAROA ROAD	S94:262290	840828	0.000	0.0560	0.518	0.108	0.0

SELECTION FACTOR :- PIPERS VALLEY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
2079	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	750303	0.000	0.0320	0.145	0.221	17.0
2192	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	750505	0.000	0.0280	0.237	0.118	8.0
2407	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	750715	0.000	0.0600	0.302	0.199	9.0
2791	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	801022	0.000	0.0220	0.000	0.000	0.0
3791	PIPERS VALLEY STREAM	AKAROA RD	S94:269287	801022	0.000	0.0220	0.000	0.000	0.0
4542	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830111	0.000	0.0060	0.058	0.110	0.0
4602	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830317	0.000	0.0120	0.117	0.106	0.0
4616	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830323	0.000	0.0060	0.045	0.143	0.0
4650	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830414	0.000	0.0070	0.043	0.168	0.0
4675	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830517	0.000	0.0200	0.181	0.110	0.0
4697	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830614	0.000	0.1870	0.497	0.377	0.0
4721	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830629	0.000	0.0890	0.474	0.209	0.0
4750	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	830810	0.000	0.0580	0.388	0.150	0.0
4822	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	831012	0.000	0.0620	0.363	0.170	0.0
4882	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	831103	0.000	0.0570	0.266	0.215	0.0
5347	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	840801	0.000	0.0690	0.339	0.203	0.0
5406	PIPERS VALLEY STREAM	AKAROA ROAD	S94:269287	840828	0.000	0.0480	0.274	0.176	0.0

SELECTION FACTOR :- BARRYS BAY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
787	BARRYS BAY STREAM	TRIB HAYLOCKS PROP	S94:233278	721005	0.000	0.0190	0.113	0.170	0.0
1161	BARRYS BAY STREAM	TRIB EMSORES PROP	S94:231275	731029	0.000	0.0120	0.099	0.121	17.0
2082	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	750303	0.000	0.0420	0.434	0.097	15.0
2190	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	750505	0.000	0.0490	0.399	0.123	9.0
2406	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	750715	0.000	0.2180	0.845	0.258	8.0
3226	BARRYS BAY STREAM	AKAROA ROAD BRIDGE	S94:242278	780405	0.000	0.0230	0.125	0.184	0.0
3789	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	801022	0.000	0.0007	0.000	0.000	0.0
3790	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	801022	0.000	0.0540	0.000	0.000	0.0
4100	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	811111	0.000	0.0730	0.375	0.195	0.0
4545	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830111	0.000	0.0300	0.347	0.088	0.0
4600	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830317	0.000	0.0330	0.373	0.090	0.0
4621	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830323	0.000	0.0160	0.280	0.056	0.0
4648	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830414	0.000	0.0270	0.338	0.079	0.0
4673	BARRYS BAY STREAM	AKAROA ROAD	S94:242287	830517	0.000	0.1400	0.561	0.249	0.0
4705	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830614	0.000	0.5490	1.090	0.502	0.0
4715	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830629	0.000	0.2810	0.797	0.353	0.0
4755	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	830811	0.000	0.2000	0.765	0.260	0.0
4832	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	831013	0.000	0.1860	0.763	0.244	0.0
4888	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	831103	0.000	0.2140	0.774	0.276	0.0
5342	BARRYS BAY STREAM	AKAROA ROAD	S94:242278	840801	0.000	0.2010	0.761	0.264	0.0
5404	BARRYS BAY STREAM	CHEESE FACTORY	S94:242278	840828	0.000	0.1310	0.635	0.206	0.0

SELECTION FACTOR :- LE BONS BAY STREAM

NO.	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
1007	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	730521	0.000	0.0610	0.653	0.093	7.0
2080	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	750303	0.000	0.1670	1.460	0.114	14.5
2195	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	750505	0.000	0.0900	1.140	0.079	10.0
2412	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	750715	0.000	0.3700	1.890	0.196	9.0
4547	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	830111	0.000	0.0490	0.416	0.117	0.0
4765	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	830811	0.000	0.2260	0.609	0.371	0.0
4830	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	831013	0.000	0.2620	0.703	0.373	0.0
4885	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	831103	0.000	0.2940	0.715	0.411	0.0
5341	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	840802	0.000	0.2650	0.755	0.351	0.0
5402	LE BONS BAY STREAM	VALLEY ROAD BRIDGE	S85:379275	840829	0.000	0.2120	0.717	0.295	0.0

SELECTION FACTOR :- OKAINS BAY STREAM

NO	RIVER	SITE	MAP. REF.	DATE	GH	DISCHARGE	AREA	MEAN V	TEMP
1073	OKAINS BAY STREAM	FRIESTAN STUD FARM	S85:353336	730801	0.000	0.0850	0.751	0.113	5.0
2085	OKAINS BAY STREAM	FRIESIAN STUD FARM	S85:253336	750303	0.000	0.1070	1.180	0.091	18.0
2191	OKAINS BAY STREAM	FRIESIAN STUD FARM	S85:353332	750505	0.000	0.0820	0.901	0.091	10.0
2411	OKAINS BAY STREAM	FRIESIAN STUD FARM	S85:353332	750715	0.000	0.3150	1.360	0.231	9.0
4143	OKAINS BAY STREAM	FRIESIAN STUD FARM	S85:353332	820211	0.000	0.0320	0.468	0.067	0.0
4548	OKAINS BAY STREAM	FRIESIAN STUD FARM	S85:353332	830111	0.000	0.0440	0.096	0.463	0.0
4629	OKAINS BAY STREAM	FREISIAN STUD FARM	S85:353332	830324	0.000	0.0330	0.088	0.375	0.0
4763	OKAINS BAY STREAM	FRIESIAN STUD	S85:353332	830811	0.000	0.2240	1.010	0.273	0.0
4827	OKAINS BAY STREAM	FRESIAN STUD	S85:353332	831013	0.000	0.2450	0.939	0.261	0.0
4881	OKAINS BAY STREAM	FRESIAN STUD	S85:353332	831103	0.000	0.2680	0.907	0.296	0.0
5345	OKAINS BAY STREAM	FRIESIAN STUD	S85:353332	840802	0.000	0.2860	0.704	0.407	0.0
5401	OKAINS BAY STREAM	FRESIAN STUD	S85:353332	840829	0.000	0.2100	0.594	0.353	0.0